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MEDICAL RESEARCH COUNCIL.

Biological
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Serials

THIRD ANNUAL REPORT

OF THE

Health

INDUSTRIAL FATIGUE RESEARCH BOARD

TO

31st DECEMBER, 1922

(INCLUDING PERSONAL CONTRIBUTIONS FROM INVESTIGATORS).

LONDON:
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To suggest problems for investigation, and to advise upon or carry out schemes of research referred to them from time to time by the Medical Research Council, undertaken to promote better knowledge of the relations of hours of labour and of other conditions of employment, including methods of work, to functions of the human body, having regard both to the preservation of health among the workers and to industrial efficiency; and to take steps to secure the co-operation of industries in the fullest practical application of the results of this research work to the needs of industry.

OFFICES:

15, York Buildings, Adelphi, London, W.C.2.

THIRD ANNUAL REPORT

# of the

INDUSTRIAL FATIGUE RESEARCH BOARD

to

31st DECEMBER, 1922.

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PART I.—REPORT OF THE BOARD.

The Board beg leave to submit their Third Annual Report for the period ended 31st December, 1922. Their previous Annual Report dealt with results obtained up to the 30th September, 1921, but for administrative reasons it has been decided that their work henceforth would be more conveniently reviewed at the end of each calendar year. The present Report accordingly covers a period of fifteen months in all.

1. Introduction.

The unprecedented industrial depression, which has characterised the whole of the year under review, has had a double effect upon the activities of the Board.

In the first place, the co-operation with industries themselves which was foreshadowed in the Board's Second Annual Report [1] has not made the progress then anticipated. Not only has the industrial atmosphere been generally unfavourable for the introduction of somewhat novel ideas and methods, but employers' and workmen's organisations have been so fully engaged with urgent economic problems that they would have had little opportunity of giving the necessary consideration to any schemes submitted by the Board. The Board, therefore, have hitherto refrained from taking any definite steps to invite collaboration, but a beginning has already been made in the case of the glass industry by the acceptance of an offer of co-operation on the part of the Glass Research Association,and as the industrial horizon eventually clears more definite progress will, it is hoped, become possible. As the Board have stated in their Second Annual Report, they have always recognised that any active co-operation with industries generally can only be brought about by gradual degrees.

Secondly, the industrial conditions prevailing during the past year have notably affected the progress of some parts of the work. The Board have already pointed out that one of the principal difficulties in those investigations which are based on observation of actual conditions of work is caused by the simultaneous operation of many variable factors, and that the extent to which definite inferences can be drawn as to the effect of any one of these factors depends very largely upon how far and over what length of time the others have remained approximately constant. During the period referred to, the variations in some of the most essential factors have been exceptionally pronounced. Short and irregular hours have been worked ; small definite orders, involving frequent changes, have largely displaced making for stock, with its steady continuous work on articles of one type ; and the normal incentives in work, which have an important influence on fatigue and efficiency, have been greatly modified. In short, conditions have been unpropitious for the prosecution of observational work of the kind on which the Board's investigations have been largely based. These disadvantages might have had some compensations, if the Board had been in a position to take full advantage of the opportunities for investigating the relation of industrial depression to fatigue and efficiency. Unfortunately, the resources at their disposal were insufficient to admit of this being done, except in the case of the cotton industry, where some knowledge has been gained as to the relation of short time to production [8].

On the other hand, a large part of the Board's work, in particular laboratory research, which is unaffected by the conditions of trade, has actually expanded in scope, and definite results, which may eventually have an important bearing on industrial occupations, have already been secured.

2. Constitution of the Board.

The Board has been strengthened by the appointment in July last of Dr. C. S. Myers, M.D., F.R.S., Director of the National Institute of Industrial Psychology, as an additional member.

3. Organisation.

The work on which the Board is engaged covers so wide a field and impinges on so many spheres of knowledge that the provision of a rather extensive standing organisation has been found necessary to ensure adequate consideration from every aspect of the results obtained before publication. This organisation has consisted essentially in the formation of three classes of expert Committees (the full constitution of which will be found in Appendix I), working in close touch with the Board.

(*a*) SCIENTIFIC COMMITTEES.

As is explained in the Second Annual Report, the supervision of the various researches and the scientific criticism of the Board's work generally has since March, 1921, been assigned to four scientific Committees appointed by the Medical Research Council in consultation with the Board, dealing respectively with Industrial Health Statistics, the Physiology of Muscular Work, the Physiology of Respiration and the Cardio-Vascular System, and Industrial Psychology. The Board, in acknowledging their indebtedness to the members of these Committees, are agreed that the opportunity thus afforded of obtaining expert scientific opinion at all stages of their work has proved to be a most valuable addition to their resources, and think that the result is reflected in the increased scientific value of their Reports. Not only have the criticisms been offered in a generous spirit and with a full recognition of the special difficulties which much of the Board's work entails, but concrete suggestions have been put forward which form the origin of many of the investigations described in the present Report.

(*b*) TECHNICAL COMMITTEES.

For the consideration of the many technical points that arise in their investigations, the Board have continued to receive the assistance of Committees composed partly of employers' and workmen's representatives from the industries concerned (together with others with special knowledge of the trade conditions) and partly of members or nominees of the Board.

The Board appreciate very highly the invaluable help received from this source, and hope that, whilst they may find it only rarely necessary to invoke the aid of certain of the Committees, they may rely on receiving from them the same guidance as in the past on any questions that may hereafter arise.

(*c*) SPECIAL COMMITTEES.

It sometimes happens that the progress of an investigation is likely to be advanced by the institution of some different method of supervision, either on account of the complexity of the problems concerned, or because their nature can be more or less clearly foreseen as belonging to two or more spheres of science. In such instances, the Board have deemed it advisable to assign the immediate supervision of the work to a special Committee containing experts on the different aspects to be considered. This practice has been followed in the cases both of the investigation into Post Office Work (p. 14), which is directed by a Committee composed of members of the Board and of the various Scientific Committees, and of the recently initiated research on legibility of type (p. 19).

4. Investigations and Researches.

In the Board's two previous Annual Reports accounts have been given of the general lines on which their work has been conducted. Roughly speaking, two methods have been adopted simultaneously, namely, research on fundamental points conducted in the laboratory, and inquiry based on observation of actual working conditions conducted in the factory. Each of these two methods has its special advantages. In the laboratory on the one hand, where conditions can be made to order, the influence of any isolated factor can be studied and even an estimation of its practical effect made, but essentially no account can be taken of other disturbing or even neutralising factors such as may be present in industrial work. Field investigation based on observation, on the other hand, although it cannot point to the relation between cause and effect with the same certainty as laboratory research, and, being based for the most part on mass data, can only indicate general tendencies, is of value not only for ascertaining the nature of the various factors operating on the large scale, but also for determining how far the results acquired in the laboratory apply or may be applied under industrial conditions. It also has the advantage of showing what actually occurs in industry, so that any conclusion which can be definitely established through confirmation elsewhere can be immediately accepted as having a direct and practical bearing on industrial fatigue and efficiency. The distinction may perhaps be shortly expressed by saying that the former method shows definitely the effect of some known cause, whilst the latter suggests the cause of some known effect.

When the Board originally entered upon their functions, they decided to adopt as the field for their first investigations certain industries, selected partly on account of their importance, partly because they appeared to offer promising features for the study of industrial fatigue, and partly because at that time work of this kind was new and the Board felt that the interest of a whole industry should be enlisted by approaching it as a unit. In accordance with this policy investigations have been carried out in the tinplate, iron and steel, boot and shoe, cotton, silk, pottery and laundry trades, and reports embodying the results either have been published or are now in course of preparation. More recently, however, and pending development of some scheme of actual co-operation with industries on the lines of the investigation now being carried out with the Glass Research Association, the Board have tended to modify their original procedure, and have taken as their objective the study of certain general subjects, not confined to any one industry but of common interest to all, following up each subject along lines which experience shows to be most promising and dealing with it both by field investigation and by laboratory research.

The following is a brief account of the investigations that have been started or completed during the past year, and of the lines of work on which the Board have embarked. It should, however, be observed that the whole of the work of the Board has a common foundation, and that though, for convenience, the investigations are separately specified, close relations exist amongst them, and the results obtained in any one of them may have a direct bearing on others.

A.—General Investigations.

(*a*) *Optimum Length of Spell, etc.*—The Board are advised that widely divergent practice exists in different industries (and even in the same industry) in regard to division of the working day, and they have accordingly decided to start an investigation on extensive lines to ascertain the best length of spell, and the best arrangement of rest pauses, for industrial occupations of different types, from the heaviest manual labour to monotonous work involving mental rather than muscular effort.

The observational side of the investigation has been primarily in the hands of Dr. H. M. Vernon, M.D. (assisted by Mr. T. Bedford), though information bearing on the point is also obtainable from the results derived from the industrial inquiries under the direction of other investigators. Further contributions to knowledge on the subject are expected from some of the researches now being carried out, in particular those on the rate of recovery after exercise (p. 15), on the static component in work (p. 16), on monotony (p. 19), and on the effect of duration of work on accuracy of movement (p. 19).

(*b*) *Accident Causation.*—A report dealing with accident causation from its personal aspect has recently been published by the Board [2]. It embodies the results of two investigations on the subject, one by Mrs. E. E. Osborne and Dr. Vernon, on the relation of temperature, etc., to accident incidence, and the other by Mr. (now Professor) B. Muscio, M.A., on the relation of accuracy of movement to (*a*) speed and (*b*) duration of work, together with a preface in which the work already done on the subject is summarised.

The Board feel that the study of the personal factor in accident causation is of great importance in connection with accident prevention, and they have accordingly decided to continue this part of the work on more extensive lines than hitherto. With the advice of the Committee on Industrial Health Statistics and the Committee on Industrial Psychology, the inquiry will be conducted in the first instance by statistical and psychological methods jointly, with the object of determining :—

(i) how far a characteristic ratio between notifiable accidents and accidents of all kinds exists for different selected occupations ;
(ii) the correlation of accident incidence with experience, age, and sex ;
(iii) the extent to which special susceptibility to accident exists [3] ;
(iv) the primary causes of such susceptibility.

For the statistical side of the work (which has been entrusted to Miss E. M. Newbold, B.A.) the Board are already indebted to several large firms for promises to collaborate. On the psychological side, a start has already been made by the initiation of laboratory research on the immediate subjective factors in accident causation, extending the work already carried out by Professor Muscio (p. 19).

(*c*) *Machine Design.*—In the course of some of the investigations evidence has been adduced to show that in the design of machinery and plant full consideration is not always given to the requirements of the prospective operator, and three apparent instances have already been mentioned in previous reports of the Board [4, 5, 6].

In some industries, such as the manufacture of typewriters and motor cars, ease of working is one of the first essentials to be taken into account, and more attention has been paid to this subject than the Board can ever hope to give. In others, however, where this necessity is less obvious, the manipulative side of design seems to have been somewhat overlooked in favour of the strictly mechanical side, and the Board are now considering the initiation of a rather close inquiry into the question of design in the case of certain types of machine, in order to ascertain whether any principles can be evolved indicating the proper relationship of machine to operator.

(*d*) *Sickness Incidence, and Mortality.*—For reasons given in their Second Annual Report, the Board have in some instances attempted to supplement their main industrial investigations with collateral inquiries into sickness incidence. Some preliminary steps were taken in 1920, under the supervision of Mr. E. A. Rusher, F.I.A., and data were extracted from the National Health Insurance records in the possession of certain approved societies in the foundry, boot and shoe, and laundry industries.

Unfortunately, a critical examination of these data by the Committee on Industrial Health Statistics has shown that owing to various disturbing factors (many of them arising from the war), the validity of any inferences based on their treatment would be open to serious doubt. In view of this opinion, the Board have felt bound to abandon any attempt to study sickness incidence by means of records dealing with the past, but they hope that it may be possible to arrange for current records to be kept on a prearranged system, under which these may be suitable for effective statistical treatment when sufficient numbers have accumulated.

Meanwhile, the Medical Research Council have initiated the following investigations dealing with sickness and mortality, which are in progress under the supervision of the Committee on Industrial Health Statistics. An inquiry has been begun into the the relative incidence of mortality, particularly mortality from phthisis, upon the residents in rural districts, and members of the same families, who have migrated to industrial towns and are employed in particular occupations. At present the investigation is restricted to the Diocese of Chelmsford, and is being carried out by the Rev. H. Iselin, M.A., in co-operation with the public health service of the County of Essex, by the collection of information from the incumbents of rural parishes.

A study of the incidence of cancer by sites and occupations is being carried out by Professor E. L. Collis, M.D., and Dr. John Brownlee on the unpublished data of the Registrar-General, and further statistical work on the differential incidence of tuberculosis is in progress, the subject being investigated from the point of view of international comparisons by Professor Collis, in collaboration with Dr. Greenwood.

B. INDUSTRIAL INVESTIGATIONS.

For the reasons given in the introduction to this Report, the tendency adopted by the Board during the past year has been to embark on work based on methods which are to a large extent independent of the trade conditions prevailing at the time (such as those involving individual study or laboratory research, or those based on examination of past records), rather than to expand the observational side of the work. So far, therefore, as their field investigations are concerned, little new ground has been broken, and work in this respect has been principally confined to the treatment of data already collected.

The position in regard to the different investigations completed or in progress, may be summarized as follows :—

(1) *Textile Industries.*—At the initial stage of the Board's existence, the advice of the Home Office was sought as to the particular industries which appeared to offer a promising field for investigation, or which on other grounds were deserving of the particular attention of the Board. Amongst the suggestions so received, special emphasis was laid on the importance of carrying out an inquiry in the cotton trade, the chief reasons for this selection being :—

- (i) The importance of the trade as the largest textile industry.
- (ii) The variety of processes involved, affording an opportunity of studying work of different kinds.
- (iii) The special conditions attaching to the industry, such as heat, noise, and humidity, which tend to make it particularly trying and have given rise to much complaint.
- (iv) The difference of opinion existing as to the best arrangement of hours and the optimum length of spell.

As the result of a preliminary survey [7] the Board decided in the first instance to confine the inquiry to the weaving section of the trade, on the grounds that of all the principal processes involved weaving seemed to be most dependent on the human factor. An extensive investigation, in the course of which a very large volume of data relating to output was collected, was accordingly started under the direction of Mr. S. Wyatt, M.Sc., and carried on under the advice of a committee containing representatives of the industry. The past year has been chiefly devoted by Mr. Wyatt (assisted by Mr. A. D. Ogden) to the working up of these data, which form the basis of a report now in the press [8]. Mr. Wyatt has also explored the atmospheric conditions in weaving sheds by means of the kata-thermometer, the results being incorporated in a separate report [9]. These investigations are important, as bearing directly on a question which has been before the industry for many years, namely, the use of artificial humidity in weaving sheds. In order to throw further light on the effects of temperature and humidity, a supplementary investigation has been completed by Mr. H. C. Weston into the kindred process of fine linen weaving, where the conditions in these respects are more extreme, and the results have now been published [5].

The principal inferences to be drawn from the combined results of the above reports may be summarized as follows :—

(i) The productive efficiency in cotton weaving is both high and uniform, though differences naturally exist as between the different classes of cloth manufactured.

(ii) Short time tends to have a depressing effect upon productive efficiency.

(iii) During the pre-breakfast spell, in a two-break day, the productive efficiency is about 2 per cent. lower than during the other two spells.

(iv) The reaction of the worker to his working conditions is masked by the predominance of the mechanical factor. When this is eliminated by calculation his working capacity is seen to undergo a gradual decrease, both throughout the day and throughout the week.

(v) The atmospheric conditions in humid cotton and linen weaving sheds are sometimes such as to involve working under physiological disadvantage. This is shown by the fact that above a certain limit of wet-bulb temperature the efficiency tends to fall, notwithstanding the more favourable effect on the yarn itself of the higher temperature and humidity. The cooling power of the air in humid sheds appears to be abnormally low, especially during summer, and experiments on the best method of overcoming this are very desirable.

(vi) Efficiency often tends to fall under a system of artificial lighting as compared with daylight, the reduction varying in amount from 11 to 5 per cent. according to the fineness of the work involved.

(vii) The initial rise and final fall in efficiency discernible in the daily work curves are not due (as is sometimes alleged) to extraneous causes, such as lateness in starting, etc., but are of subjective origin, and represent a real quickening up and slowing down.

(viii) Productive efficiency in weaving is more dependent upon physical factors, such as variations in the yarn, quality of the size used, etc., than upon the variations in working capacity on the part of the operative.

Lastly, some further work has been carried out in the silk industry, which was also originally brought to the notice of the Board by the Home Office, largely on the grounds that the special fineness of many of the processes gives the industry an individual character. Some investigation has already been made into the conditions of this industry [10], and during the past year a second contribution [11] by Mr. P. M. Elton, M.Sc., dealing with the study of individual efficiency in silk weaving, was generously presented to the Board by Messrs. Grout & Co., Ltd., Great Yarmouth.

A comparison of the extent of individual differences in performance shows that, while the performance of any given weaver remains at about the same level irrespective of the quality of the cloth woven, no definite line of demarcation exists between good and bad weavers, the two classes merging into one another by insensible degrees. By a detailed analysis of the methods adopted by selected weavers, certain principles underlying good and bad performance in weaving are established and the importance of preliminary training is indicated. A further practical point brought out in the investigation is the much greater dependence of productive efficiency on the operative in comparison with cotton weaving, as is shown by the large but consistent differences in loom efficiency manifested as between one weaver and another.

(2) *Boot and Shoe Industry.*—Some additional information on variations in individual output for several processes in boot factories has been collected by Mr. T. Bedford and published by him elsewhere [12].

(3) *Pottery Industry.*—In 1920 the Board accepted an invitation from the National Council of the Pottery Industry to participate in an inquiry dealing with the construction and ventilation of drying stoves in potters' shops, a question which has been under the consideration of the industry for many years. At the time when the Board were approached, an interim report on the subject, embodying the results of an inquiry by a Subcommittee of the National Council, had already been published. This, however, was recognised to be only a first contribution, and the help of the Board was invited in respect of a further inquiry on physiological lines, dealing principally with the atmospheric conditions of potters' shops. The investigation, which was entrusted to Dr. H. M. Vernon (assisted by Mr. T. Bedford), has now been completed, and the results published [13].

Two main lines of inquiry were pursued. First, observations were made on the general atmospheric conditions of potters' shops chiefly from the points of view of temperature and cooling power. These indicate that in most potters' shops the temperature is higher and the air velocity lower than in workrooms in other industries, such as the boot and shoe and the engineering trades, in which the operatives are engaged in active work comparable with that of the potters. These conditions, however, seem to be partly due to a preference on the part of the potters to a temperature which is somewhat higher than that found most comfortable in other industries, possibly owing to the fact that they are constantly handling cold, moist clay. Further, in the case of operatives who are in constant motion the effective velocity of the air currents (and consequently the cooling power) is greatly increased by the body movements made by them.

Secondly, the different types of stove were studied in order to ascertain whether means could be found of retaining the present drying powers of the stoves, and even of increasing them, and yet of reducing the flood of hot air which passes from them into the shops. The results are chiefly of technical interest, suggestions being made for preventing or reducing the escape of hot air and the relative importance of temperature and ventilation in the drying of ware discussed.

(4) *Laundry Industry.*—This industry was originally selected for special study, on the recommendation of the Home Office, for two reasons. First, the extensive use of steam and gas necessarily produces atmospheric conditions which it was thought might be usefully explored in relation to the effect of environment on fatigue and efficiency. Secondly, since the hours allowed by law and actually worked are far more irregular than in any other class of factory, a good opportunity seemed to be afforded for the investigation of the relation of hours of labour to fatigue by means of the variations in the daily hours worked throughout the trade.

The Board accordingly resolved that a somewhat extensive investigation into the conditions of the industry should be undertaken under the direction of Miss M. Smith, M.A. (assisted by Miss L. Baker). This has now been completed, and the results published [6].

Unfortunately, as against the advantages described above, experience has shown that the trade possesses several features which have rendered investigation particularly difficult. As the Board have pointed out on several previous occasions, work under practical conditions is necessarily subject to the simultaneous operation of a large number of variable factors, and before the relation to fatigue and efficiency of any factor can be adequately explored, it is essential that the other factors shall be rendered constant, either actually or by calculation. In laundries, however, the great and unforeseen differences in the class of articles dealt with have introduced an element of variation which has not only made the usual technique, as adopted by the Board in most of the other investigations, inapplicable in this case, but has defied all attempts to secure any real degree of the necessary constancy. It follows, therefore, that whilst much valuable information has been gained on individual differences and on the general conditions prevailing in the trade, any inferences drawn as to general tendencies (such as the effects of hours of work) can only be regarded as tentative and as showing the desirability of further investigation.

The main conclusions reached may be summarised as follows :—

(i) The atmospheric conditions in laundries compare unfavourably, as regards temperature and cooling power, with other industries investigated.

(ii) Individual differences play a predominant part in efficiency.

(iii) The interpolation of short rest pauses into spells of moderate length appears to have a beneficial effect.

(iv) The application of a modified form of output test to individual workers in different departments points to a lowering of working capacity in the afternoon as compared with the morning, and this effect becomes more pronounced during periods when a ten-hour day is substituted for a nine-hour day. Similar results were obtained when individuals were subjected to a psychological test. In both instances, however, the effects tended to be masked by other factors, such as bodily comfort and mental conditions.

(v) There is no evidence that laundry work, when conducted under reasonably good conditions is detrimental to health.

(5) *Glass Industry.*—An important new development has occurred in the case of an investigation conducted by Mr. E. Farmer, M.A. (assisted by Mr. R. S. Brooke, M.C., M.A., and Mr. E. G. Chambers, B.A.) in the Glass Industry. Part of the expenses incurred is being defrayed by the Glass Research Association, and the direct control of the work has been transferred to a Committee of the Association, with two nominees of the Board as additional members. (See Appendix I.) The final results of the investigation are not yet available.

(6) *Latch and Lock Industry.*—At the request of the Secretary of the Latch and Lock Manufacturers Association a preliminary survey of the industry was undertaken by Mr. E. Farmer, and the question has now been referred to the National Institute of Industrial Psychology.

(7) *Post Office Work.*—As stated in the Second Annual Report, the Postmaster-General has referred the following four specific questions to the Board :—

(*a*) At offices where it is impossible to arrange continuous eight-hour duties for all the staff, is it preferable to split the duties into two halves, or to arrange long and short continuous duties on alternative days? Where split duties are worked, what is the ideal interval between the two halves from the point of view of industrial fatigue?

(*b*) Are changes of work within a spell of duty in telegraph offices (either to similar work or to different work) beneficial to the individual or otherwise?

(*c*) Can any means be suggested for minimising or preventing the liability to telegraphists' cramp (Morse or Baudot)?

(*d*) Is it desirable that the training of telegraphists should be intensive, or that it should be spread over a fairly long period with intervals of non-manipulative work?

By subsequent agreement with the Post Office, the investigation was provisionally limited to the third of these, dealing with the important subject of telegraphists' cramp. In pursuance of this arrangement, Mr. E. Farmer and Miss May Smith have been engaged in making a series of observations in the Central Telegraph Office, with the object, first, of studying the causes leading to cramp, and secondly, of measuring some of its objective symptoms, in order to suggest means for its prevention or amelioration.

On account of the many scientific aspects involved, the immediate control of this investigation has been entrusted to a special committee constituted from the Board and the different Scientific Committees. (See Appendix I.) The Committee have advised the Board that in order to arrive at conclusions of scientific value, further and more detailed study with a more refined technique will be necessary, and that for this reason the results obtained up to the present should be withheld from publication. In the meantime, an outline of the methods adopted and of the proposed future lines of inquiry is given in Appendix II.

C. RESEARCHES.

Collaterally with the observational side of the Board's work a series of researches on fundamental points are in progress under the immediate control of one or other of the Scientific Committees.

(*a*) *Researches relating to Muscular Work of different Kinds.*

A series of three important researches on this subject has been initiated by the Committee on the Physiology of Muscular Work.

1. *Rate of Recovery after Exercise.*—The rate of recovery (as measured by the oxygen consumption) after muscular exercise of different kinds and different durations is being studied at the University of Manchester by Mr. H. Lupton, M.Sc., under the supervision of Professor A. V. Hill, F.R.S. The results hitherto obtained by him [14, 15] may be summarised as follows :—

(i) In the case of horizontal walking and running (*i.e.*, muscular movement involving no external work), below a certain speed the oxygen consumption increases approximately as the square of the speed ; above this speed, any increase in speed is not accompanied by an increase in oxygen consumption, the limiting rate of oxygen consumption being probably determined by the maximum capacity of the lungs and heart to supply oxygen to the tissues.

(ii) In the case of muscular movements involving external work there is an optimum value of the speed at which the efficiency is a maximum. During work at this speed the efficiency of the movement has a value of 25 per cent.

(iii) On the taking of muscular exercise the body " goes into debt " for oxygen to an extent depending on the severity of the exercise, and most of the deficit is recovered within a few minutes of the cessation of the exercise.

(iv) At the beginning of exercise an oxygen deficit is set up, and this is maintained until the recovery period which immediately follows cessation of the exercise. For rates of energy expenditure below the limit set by the capacity of lungs and heart, the total excess oxygen during recovery is equal to this deficit produced at the beginning of the exercise, such deficit increasing with the speed but remaining constant for any given speed, however prolonged the exercise. Hence such exercise from the point of view of the muscular machine might be kept up indefinitely. For rates of working beyond the limit set by the capacity of lungs and heart the deficit of oxygen increases with the time. In other words, lactic acid accumulates until exhaustion ensues. The limiting speed varies with the individual, being in the neighbourhood of seven miles an hour for horizontal running.

Apart from their scientific interest, these results are important from the industrial point of view, as indicating first the existence of an optimum speed for strenuous muscular work, and secondly a method for determining the limiting speed below which muscle exhaustion as the result of accumulation of waste products does not occur.

2. *Muscular Exercise with Special Reference to Women, and the Static Component in Work.*—Research on the static component of exercise (*i.e.* of the effects of the factors in exercise which involve no movement and therefore no work in the mechanical sense, such as pressure), and on muscular work for women, has been conducted at the University of Glasgow by Miss E. Bedale and Mr. G. McCallum (working under Professor E. P. Cathcart, F.R.S.), the results of which will probably have a direct bearing on many industrial operations. They found that in an effort which was gradually changed from being definitely positive, *i.e.*, productive of external mechanical work, to being definitely static, *i.e.*, non-productive of external mechanical work, there came a rate of performance when the cost per kilogrammetre rose and continued to rise as the effort became more static. The rise in cost was associated with a marked decline in the mechanical efficiency with which the effort was made. They further found that fatigue was a very pronounced feature of static effort.

Professor Cathcart is also investigating the maximum pull and push which can be done by the average human subject.

3. *Tests for Physical Efficiency.*—The investigation of different tests for physical efficiency is being undertaken at Guy's Hospital, London. Observations based on pulse phenomena have now been published by Mr. W. D. Hambly, B.Sc.; Dr. G. H. Hunt, M.D.; the late Major L. E. L. Parker; Professor M. S. Pembrey, F.R.S., and Mr. E. C. Warner, B.Sc. [16]. They show that the "pulse ratio" (*i.e.*, the ratio between the pulse rate for the two minutes

following exercise and the pulse rate at rest) is a good indication of physical fitness in the case of mild muscular exercise, but that this does not hold good for more severe exercise, such as running a mile. In the strenuous exercise the fittest men are those who showed the greatest percentage rise in the pulse rate, and the greatest percentage fall towards the resting value. These results are important industrially, as indicating a possible means of testing individuals for fitness for certain kinds of work.

In addition, two investigations on related lines are being conducted under the supervision of the Committee on Industrial Health Statistics. A biometric study of the candidates for the Royal Air Force, with particular reference to the relation between ordinary physical measurements and vital capacity, is being carried out by Dr. Lucy Cripps, Dr. Major Greenwood, and Miss E. M. Newbold, and the performance by different classes of young women of the physiological tests introduced by Wing-Commander Flack is being investigated by Dr. Lucy Cripps.

Apart from these main researches, some other work bearing on muscular activity of different kinds has been carried out in connection with other investigations.

4. *Effect of Rest-pauses and Change of Posture.*—A research on the effects of rest pauses and change of posture on fatigue in muscular work involving maximal effort (a preliminary account of which has now been published [17]), has been carried out by Dr. Vernon, as part of an investigation into the influence of rest-pauses on heavy work.

5. *Effect of Atmospheric Conditions.*—The relation of atmospheric conditions, and in particular the cooling power, to efficiency in muscular work is being explored by Dr. Leonard Hill, F.R.S., and Dr. J. Argyll Campbell, M.D., on behalf of the Committee on Physiology of Respiration and the Cardio-vascular System.

6. *Muscular Control.*—An investigation carried out by Professor Muscio, primarily with the object of studying accident causation [2], has shown that in the case of light muscular work of a monotonous type, accuracy of movement within certain limits rapidly diminishes as the speed of work is increased, but actually increases over a continuous spell of 3½ hours when the speed is constant.

7. *Motor Capacity.*—A research on motor capacity carried out by Professor Muscio, in connection with vocational selection, and described on p. 18, has some bearing on muscular work.

(*b*) *Researches not primarily concerned with Muscular Work.*

Apart from the work that is being carried out by means of field investigation, certain researches on specific points, chiefly of a psychological nature, have been initiated under the control of the Committee on Industrial Psychology.

1. *Motor Capacity.*—Professor Muscio has carried out a research into motor capacity, a term which he coins on the analogy of mental capacity [18]. It is well known that many mental tests tend to correlate positively, some of them so highly that the term "general mental ability" is used to account for the fact. Mr. Muscio's object is to ascertain whether there is similarly a "general motor ability"—in the sense that a number of different motor tests tend to correlate positively and highly—that is to say, the aim of his research is to discover whether the person of good "general motor capacity" can be detected by suitable motor tests, just as the person of good "general mental capacity" can be detected by suitable intelligence tests. His conclusions, which are negative, are as follows:—

(i) There is no "motor type." Terms such as "motor dexterity" or "practical ability" are misleading, since a person's relative performance in any one motor test does not normally represent a general motor test performance level, that is, a relative performance level which will be attained in any other motor test.

(ii) Motor capacities are relatively independent of intelligence For since motor tests do not correlate with one another positively to any appreciable degree, they cannot in general correlate positively with any other tests, and therefore not with intelligence tests.

(iii) From the point of view of vocational guidance, the practical conclusion is that every occupation which consists mainly of a routine performance of specific movements will require specific vocational tests; that is, motor (vocational) tests for a given "motor" occupation must be tests of just those motor capacities that function in that occupation.

2. *Vocational Selection.*—A research on vocational selection has recently been undertaken by Mr. Cyril Burt, M.A., with the assistance of Miss May Smith, Miss L. Baker, and Miss Frances Gaw. The lines on which this investigation is proceeding are to ascertain by means of tests the characteristics of children on leaving school, and eventually to find how far the results of these tests correlate with subsequent efficiency in the industrial vocations entered upon. The work is being carried out in co-operation with the National Institute of Industrial Psychology, with the help of the Ministry of Labour and the London County Council Education Authority.

3. *Personal Qualities Demanded in Weaving.*—Research on the intelligence and special aptitudes required in the occupation of weaving is being carried out at the University of Manchester by Mr. James A. Fraser, M.A., under Professor T. H. Pear, M.A.

4. *Accuracy of Movement.*—The factors affecting accuracy of movement are being explored by laboratory methods (on lines roughly similar to those adopted by Mr. Muscio in Report No. 19), by Miss M. Vernon (working under Mr. F. C. Bartlett, M.A.), as a contribution to the main investigation on accident causation.

5. *Monotony.*—The nature of monotonous work and of work involving mental rather than muscular effort, is being studied at Manchester University by Miss I. Burnett, under the supervision of Professor T. H. Pear, M.A.

Some laboratory experiments have been conducted by Mr. Wyatt for the purpose of comparing the effects of continued repetition work throughout the day with hourly changes in the form of activity. The results, which are not yet published, illustrate the effects of continuity and change in the form of acitivity, and their relation to monotony and fatigue. A supplementary investigation on similar lines has also been carried out in the works of a firm of manufacturing chemists.

6. *Menstrual Period.*—The psychological effects of the menstrual period are being investigated by Miss S. M. Sowton, under the direction of Dr. C. S. Myers.

7. *Coloured Inks and Papers.*—Research on the optimum contrast between coloured and tinted inks and papers, such as are used in certain official forms of return—a question referred to the Board by the Post Office and H.M. Stationery Office through the Advisory Committee on Lighting of Public Buildings—is being carried out by Mr. F. C. Bartlett.

8. *Legibility of Type.*—In April, 1920, a Committee was appointed by a Treasury Minute to select the best faces of type and modes of display for Government publication. Their Report [19], issued in 1922, contains a recommendation that the Medical Research Council should be approached with a view to the inception of an inquiry on physiological and psychological lines into such questions as legibility and the optical properties of paper and ink with reference to eye strain. The Medical Research Council have resolved to act on this recommendation, and to place the inquiry within the general scope of the Board's work. As the first step, a special Committee has been appointed under the Chairmanship of Sir John H. Parsons, F.R.S., to initiate research on the subject (see Appendix I.).

5. External Relations.

The Board have again to acknowledge the assistance and advice received from various Government Departments, in particular the Factory Department of the Home Office, the Ministry of Labour, and the Ministry of Health.

Close relations have continued with the foreign organisations established with aims similar to those of the Board, and invitations for the giving of series of lectures on the work of the Board have been received from Sweden, Norway, and Japan.

Arrangements are now under consideration, by which it is hoped that more intimate co-operation with the National Institute of Industrial Psychology may be secured.

6. Publications.

Since the appearance of the Board's last Annual Report, seven reports have been published, bringing the total number issued by the Board to 23. A complete list of these with summaries of the contents of each appears in the Supplement on page 76. In addition to the Reports themselves, a number of papers by the investigating staff have appeared in various scientific journals.

Part II of the present Report contains personal contributions from the senior members of the investigating staff, dealing with different general topics and based on several years experience of the work. In the sections entitled " Some Considerations Concerning Technique " and " The Use of the Sample in Investigation," Mr. Farmer and Miss Smith deal respectively with the general methods which can be adopted in investigations of the kind on which the Board is engaged and with some of the special difficulties encountered. Mr. Wyatt contributes " Some Observations on Industrial Conditions with Special Reference to Cotton Weaving," in which certain points that appear to require further investigation in cotton weaving are discussed. Two articles by Dr. Vernon appear, in one of which our present knowledge on the relation of atmospheric conditions to industrial efficiency is summarised and in the other suggestions for future lines of investigation in the pottery industry (based on Report No. 18) are made. Finally, Mr. H. C. Weston is responsible for a note dealing with machine design in relation to the working efficiency of the operative.

7. Conclusion.

In the prosecution of their work the Board have always kept in mind that the results of their investigations would probably have a dual character. Industrial inquiries based largely on observational methods, of the kind mostly undertaken up to now, must often disclose facts of primary interest to the trade concerned without, so far as can be seen at present, involving any principles of wider application. An illustration exists in Report No. 18 (Two Investigations in Potters' Shops), part of which is concerned with technical matters for many years regarded by the pottery trade as of special importance. The Board, however, have regarded this aspect of their work as secondary to their main objective, namely, the study of fatigue and efficiency on general lines. On the other hand, any given investigation may sometimes produce results indicative of, but not definitely establishing, some principle governing fatigue and efficiency. In such instances, the findings of one isolated report must necessarily be regarded merely as hypothetical ; but as the same inference emerges from some other independent source or sources, such as an investigation in another industry or fundamental research in the laboratory, the probability that the original hypothesis is correct is greatly increased, until it can eventually become definitely accepted as a statement of fact.

Up to the present, the Board have been engaged largely in pioneer work, that is, in feeling their way through the many opportunities existing in the industrial field ; but the time is now arriving when, as the combined result of their investigations, principles of general application, open to no reasonable doubt, are beginning to appear.

The Second Annual Report of the Board included an analysis of their work, formed by dissecting the different reports then published and collating the results under certain specified headings, so as to allow the inferences drawn from their investigations to be compared on common ground. At that time, however, the work of the Board had not progressed far enough to admit of any important advance in knowledge being indicated through more than one channel. The Board have thought it advisable still to await the acquisition of further knowledge before preparing another analysis, but they hope that at the end of another year they may be able definitely to point to the establishment of certain fundamental principles governing fatigue and efficiency. In the meantime, however, some examples of how independent inquiries may be used to confirm one another's findings may be quoted.

In the weaving of certain kinds of cotton cloth moisture is purposely injected into the air of the room in order to aid the process of manufacture. Continuous objection to this practice on the part of the operatives, especially during the hot summer months, has led to the appointment of several committees of inquiry. The physiological evidence given before the most recent of these committees pointed to the fact that work of the type of weaving is carried on under disadvantageous conditions when the wet-bulb temperature exceeds a limit variously given as 70° to 75°F. Collateral inquiries also showed that at temperatures approximating to these the body temperature of the operatives tends to rise as work proceeds. Two recent reports of the Board now confirm almost exactly the conclusions arrived at above. It has, in fact, been shown that in cotton weaving the time taken by the weaver to deal with each breakage increases, within limits, as the wet-bulb temperature rises, and that in the kindred process of fine linen weaving efficiency falls to a marked degree when the wet-bulb temperature reached 73°F. Thus, four independent inquiries, based on different methods, point to the same result, which shows that amelioration of conditions in this respect is in the direct interest of the industry.

Another factor on which a definite pronouncement can be made is lighting, at least in its relation to weaving. In an earlier report evidence was adduced suggesting that in silk weaving the effect of even a good system of artificial lighting is to reduce productive efficiency by about 10 per cent. as compared with natural lighting. This inference now receives support from two recent reports. In the weaving of fine linen (comparable in respect of fineness with silk weaving) the same effect has been detected, and in its numerical value (11 per cent.) coincides very closely with that previously observed. In the coarser process of cotton weaving, the effect may again be present ; but, as would be expected, it is less pronounced, amounting in one instance to 5 per cent.

A third example of confirmation received from different sources, occurs in connection with the study of accident causation. In recent years, some controversy has taken place as to the relative importance of fatigue and speed of work as factors in accident incidence. Dr. Vernon has expressed the opinion that the latter is the more important, on the grounds that the output curve and the curve giving hourly accident incidence usually correspond closely, whilst there may be no increase in accidents at the end of a spell of work when fatigue would naturally be expected to manifest itself. Although much investigation is necessary before this difficult and complex question can be regarded as definitely answered, Dr. Vernon's hypothesis has received some confirmation from a laboratory research conducted by Professor Muscio, which shows that accuracy of movement actually increases over a spell of work, when the speed of work is constant, but rapidly diminishes as the speed of work is increased above a certain rate.

In regard to the future a certain difference in the scope of the Board's inquiries, namely, the tendency to concentrate on general subjects rather than on particular industries, has been already mentioned. This, however, affects the field of work rather than the actual methods of investigation, in which, in the opinion of the Board, no radical modifications are called for. They propose, therefore, to continue their work on the same lines as hitherto, and notwithstanding the slightly different outlook involved in their programme of work, they will still be prepared to consider any general problems of interest to a particular industry that may be referred to them. Apart from questions on which a real difference of opinion may exist, there are many phenomena in industry, the occurrence of which is almost universally accepted. In the opinion of the Board, it is important that these should not be ignored on that account, but that they should be fully studied until definite numerical values can be attached to them. For instance, the pre-breakfast spell in the two-break day is known to be relatively unproductive in some occupations ; and, again, it is generally agreed that in certain classes of weaving the difficulty of the work increases during periods when artificial light is used.

As the result of the Board's investigation, some indication of the actual numerical effect of each of these is available, which not only enables their subjective influence to be gauged with approximate accuracy, but also shows that the selection of the best conditions is a matter of interest to all concerned.

Finally, there are clear indications that interest in work of the kind carried out by the Board is rapidly growing. This is shown not only by the number of requests for information and of spontaneous suggestions for investigation received during the past year, but also by the expansion in the functions of the recently formed National Institute of Industrial Psychology. Abroad, too, the same development is proceeding. Institutions concerned with fatigue study or vocational guidance, some of them in enjoyment of subsidies from public funds, exist in America, Belgium, Spain, and Germany, and an Association with functions akin to those of the Board, financed partly by the State and partly by industrial organisations on lines very similar to those outlined in the Board's Second Annual Report in forecasting their own future, has been recently formed in Japan.

The Board record with deep regret the following deaths that have occurred since the issue of their last Annual Report :—

Dr. Edward J. Hopkinson, M.P., was an original member of the Board, joining it in July, 1918. During the early stages of the Board's existence his long experience of the engineering industry, associated with his extensive scientific knowledge, was of special value in enabling them to frame a definite scheme of investigation, and although ill-health subsequently prevented him from taking part in the Board's deliberations, he retained an active interest in their work, and frequently gave them the benefit of his views on matters upon which he was specially qualified to advise.

Dr. W. H. R. Rivers, F.R.S., joined the Committee on Industrial Psychology on its appointment by the Medical Research Council in June, 1921. Though he was in actual touch with the Board's work for only a short time, his interest in it was at once aroused, and he showed a full realisation both of its difficulties and of its future possibilities. The absence of his great scientific attainments, of his sound and kindly criticism, and of the wide outlook he always displayed will remain an irreparable loss to the Committee and the Board.

Miss Edith C. Allen, who at Cambridge University gained Honours in the Mathematical Tripos, Part I, joined the staff of the Board as an Assistant Investigator in May, 1919, and was appointed Secretary to the Committee on Industrial Health Statistics on its formation in June, 1921. Her untimely death has deprived the Committee and the Board of a worker of great ability and promise.

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APPENDIX I.

COMMITTEES RELATED TO THE BOARD.

A.—Scientific Committees.

INDUSTRIAL HEALTH STATISTICS.

Major Greenwood, M.R.C.P. (Medical Officer, Minister of Health), (*Chairman*).

John Brownlee, M.D., D.Sc. (Director of Statistics, Medical Research Council).

E. L. Collis, M.D., M.R.C.P. (Talbot Professor of Preventive Medicine, Cardiff).

A. Henry, F.I.A. (Deputy Government Actuary).

Leonard Hill, M.B., F.R.S. (Director of Applied Physiology, Medical Research Council).

L. Isserlis, M.A., D.Sc. (Statistician to the United Kingdom Chamber of Shipping).

A. S. MacNalty, M.D. (Medical Officer, Ministry of Health).

G. Udny Yule, C.B.E., M.A., F.R.S. (University Lecturer in Statistics, Cambridge).

E. L. Faning (*Secretary*).

PHYSIOLOGY OF MUSCULAR WORK.

E. H. Starling, C.M.G., M.D., F.R.S. (Professor of Physiology, University of London), (*Chairman*).

E. P. Cathcart, M.D., F.R.S. (Professor of Physiology, Glasgow University).

A. V. Hill, O.B.E., Sc.D., F.R.S. (Professor of Physiology, University of Manchester).

M. S. Pembrey, M.D., F.R.S. (Professor of Physiology, Guy's Hospital).

B. A. McSwiney, M.B. (*Secretary*).

PHYSIOLOGY OF THE RESPIRATORY AND THE CARDIO-VASCULAR SYSTEMS.

Leonard Hill, M.B., F.R.S. (Director of Applied Physiology, National Institute for Medical Research), (*Chairman*).

J. C. Bridge, F.R.C.S.Ed. (H.M. Medical Inspector of Factories).

Winifred Cullis, D.Sc. (Professor of Physiology, University of London).

Wing-Commander Martin Flack, C.B.E., M.B. (Director of Medical Research, Royal Air Force).

INDUSTRIAL PSYCHOLOGY.

Henry Head, M.D., F.R.S. (Member of the Medical Research Council), (*Chairman*).

Cyril Burt, M.A. (Psychologist to the London County Council).

C. S. Myers, C.B.E., Sc.D., M.D., F.R.S. (Director of the National Institute of Industrial Psychology).

T. H. Pear, M.A. (Professor of Psychology, University of Manchester).

Sir Charles Sherrington, G.B.E., Sc.D., Pres.R.S. (Professor of Physiology, University of Oxford).

B.—Industrial Committees.

TEXTILE INDUSTRIES.

Kenneth Lee, LL.D. ; R. R. Bannatyne, C.B. (Member of the Board) ; E. L. Collis, M.D., M.R.C.P. (Member of the Committee on Industrial Health Statistics) ; Winifred Cullis, D.Sc. (Member of the Committee on Physiology of Respiration) ; C. S. Myers, C.B.E., M.D., F.R.S. (Member of the Board) ; John Jackson, O.B.E. (H.M. Deputy Chief Inspector of Factories).

John Taylor and Cephas Speak (*Representatives of the Cotton Industry*).

S. Courtauld, J. Downes, W. Frost and F. Saward (*Representatives of the Silk Industry*).

METAL INDUSTRIES.

W. L. Hichens (Member of the Board) ; E. L. Collis, M.D. ; C. S. Myers, M.D., F.R.S. ; H. J. Wilson (H. M. Deputy Chief Inspector of Factories).

H. L. Davies, E. H. Lewis, T. Phillips, P. W. Whitehead, T. Griffiths, M.P., Ll. Carter, H. Hall, W. T. Griffiths, J. Walker (*Representatives of the Iron and Steel Industry*).

W. Morris and Ivor Gwynne (*Representatives of the Tinplate Industry*).

POTTERY INDUSTRY.

T. M. Legge, C.B.E., M.D. (H.M. Medical Inspector of Factories) ; E. L. Collis, M.D., M.R.C.P. ; Winifred Cullis, D.Sc. ; Mona Wilson (Member of the Board) ; E. A. R. Werner, O.B.E. (H.M. Superintending Inspector of Factories).

Joseph Burton, S. Clowes, A. Hollins, A. H. Maddock (*Representatives of the Pottery Industry*).

GLASS INDUSTRY.*

R. S. Biram ; G. E. Alexander, O.B.E. ; C. C. Paterson, O.B.E. ; S. N. Jenkinson, M.B.E. ; F. G. Clark ; J. Forster, O.B.E. ; E. Meigh, M.B.E. ; T. C. Moorshead ; J. Northwood ; E. J. Purser (*Representatives of the Glass Research Association*).

E. L. Collis, D. R. Wilson (*Nominees of the Industrial Fatigue Research Board*).

INDUSTRIES SPECIALLY AFFECTING WOMEN.

Winifred Cullis, D.Sc. (*Chairman*) ; R. R. Bannatyne, C.B. ; Mona Wilson ; Hilda Martindale, O.B.E. (H.M. Superintending Inspector of Factories).

J. J. Stark and Agnes North (*Representatives of the Laundry Industry*).

C.—Special Committees.

POST OFFICE WORK.

C. J. Bond, C.M.G., F.R.C.S. (Member of the Board), (*Chairman*) ; C. Burt, M.A. (Member of the Committee on Industrial Psychology) ; M. Greenwood, M.R.C.S. (Chairman of the Committee on Industrial Health Statistics) ; M. S. Pembrey, F.R.S. (Member of the Committee on Physiology of Muscular Work) ; Mona Wilson (Member of the Board).

LEGIBILITY OF TYPE.

Sir John H. Parsons, C.B.E., D.Sc., F.R.S. (*Chairman*) ; F. C. Bartlett, M.A. (Director of the Psychological Laboratory, Cambridge) ; H. Hartridge, M.D. (Demonstrator in Physiology, Cambridge) ; L. A. Legros, O.B.E., M.Inst.C.E. ; E. Schuster, D.Sc. (*Secretary*).

APPENDIX II.

OUTLINE OF A PRELIMINARY STUDY OF TELEGRAPHISTS' CRAMP.

Aim.

(1) To study the causes leading to cramp.

(2) To measure some of its objective symptoms, in order to suggest means for its prevention or amelioration.

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* This Committee is constituted on a special basis with the co-operation of the Glass Research Association (*see* p. 14).

Methods Adopted.

Eighty-seven men and women telegraphists were interviewed, half of whom were officially recognised as suffering from cramp, and the others officially regarded as free. Each telegraphist was asked to do certain tests and also to discuss the causes of cramp from his own point of view. The study consisted of two parts :—

(I) An experimental inquiry aiming at objective measurement by the application of the following tests :—

(*a*) A piece of apparatus specially designed to measure the degree of pressure exerted in sending a telegraphic message, (*a*) at a normal pace, (*b*) at a quick pace.

(*b*) An ergograph to measure the fatiguability, amount of work done in a given time, and the power of sustaining effort.

(*c*) A "dotting" test to measure voluntary attention and accuracy of motor co-ordination.

(II) A personal inquiry.

Results.

(1) Statistical treatment of the results of the tests showed that the cramp group differed from the non-cramp group in the types of their neuro-muscular reactions. Although the data obtained from this preliminary study are not sufficient to assign definite causes for the various types of cramp manifested, yet they are sufficient to show that a new line of inquiry has been opened up, justifying future experimental work.

(2) The biographical records throw considerable light on the relation between cramp and such factors as length of service, hours of work, type of key, different styles of sending, rhythm and optimum speed. They also show that there were various types of disability, ranging from general disability in the arm for specific muscular activities to particular disability for telegraphic work.

Suggestions for Future Work.

(1) Further experimentation is necessary in order to correlate the above factors and to discover how far they are connected with different types of neuro-muscular reaction, styles of sending and methods of training, etc.

(2) It is also important to determine how far certain of the presumed causes of cramp are native or acquired, and how far they can be modified by preventive treatment.

(3) Another point which needs further investigation is to determine how far cramp can be differentiated from fatigue and how far correlated with it. For this purpose it will be necessary to find out by experimental means how far the objective records obtained from the tests are affected by diurnal and cumulative fatigue, and in the event of any direct relation being apparent, to discover how far this varies according to differences in the type of muscular reaction.

It is impossible to lay down clearly beforehand all the requirements of a research, but as far as can be foreseen the best method of procedure will be :—

(*a*) to test groups of learners in the training school, and

(*b*) to examine further groups of adult telegraphists.

Experiments should also be made on discontinuing manipulative work for certain periods, in order to see if there is a resultant change in the test records. This is a most important part of the research, and careful work should throw light on the problems of remedial treatment, the work in the school primarily dealing with prevention.

If the necessary facilities are forthcoming it seems not unreasonable, judging from the results already obtained, to expect that considerable light will be thrown upon the causes of cramp, and practical suggestions made regarding its prevention and curative treatment.

PART II.—PERSONAL CONTRIBUTIONS FROM INVESTIGATORS.

A.—SOME CONSIDERATIONS CONCERNING TECHNIQUE.

By E. Farmer, M.A.

Methods of Inquiry.

Scientific inquiry divides itself into observation and experimentation. The two are closely connected and in most sciences the employment of both methods is possible, and wherever it is possible it is always desirable. Some sciences, e.g., astronomy, by the nature of their subject matter depend entirely upon one of these methods. Where it is impossible to vary the conditions determining the interaction of the phenomena studied by the science, observation is the only method applicable. This does not mean that such sciences are therefore less exact than those in which it is possible to employ the experimental method, for the contrary is often the case. The exactitude of an observational science will depend upon two main factors, one connected with the scientist and one connected with the subject matter. Exactness depending on the scientist is determined first by power to observe accurately, and secondly by ability to formulate correct hypotheses based upon and explaining the observed phenomena. Exactness depending on the subject matter will be determined by whether it lends itself to exact mathematical treatment, or whether it lends itself only to problematic reasoning. Astronomy may be taken as an example of an observational science where mathematical exactitude can be attained, and geology as an observational science involving conclusions of varying degrees of probability.

The sciences in which the Industrial Fatigue Research Board are interested in their study of fatigue and the problems connected with it, are concerned with human action under given conditions. These sciences belong to what may be called the biological group (to distinguish them from the physical sciences, such as chemistry), and are heirs to all the uncertainties connected with the interpretation of human behaviour ; the nature of the subject matter precludes the possibility of arriving at conclusions of absolute certainty—the most that can be expected is carefully to estimate the probability of the conclusions.

Observational Methods.

The observational method can be employed for the study of fatigue in two ways :—(1) By the collection of data from the records of firms ; and (2) by the collection of data by a skilled observer in a factory.

Under the former method, information can be gained from examining the records of various firms on such questions as output, accidents, lost time, labour turnover, and it is sometimes possible to compare data collected in this way with similar data collected from firms or industries employing different methods. The scientific worker employing this method has considerable difficulties to contend with. In the first place, factory records are kept for industrial and not for scientific purposes, so that it is often difficult to obtain records that have been kept in such a way as to lend themselves to the purposes of fatigue study. Even when such records have been found, it is difficult to make a strictly accurate comparison between the data obtained in one firm and the data obtained in another firm employed in the same industry. Conditions vary to such an extent from firm to firm that the very greatest care is necessary in comparing their records.

Industrial records are rarely so complete as might be desired, so that it sometimes happens that one change affecting results may be recorded, while another that accompanied it may not be recorded at all. For instance, a change in the length of spell may be introduced which has an effect on output, but a change in method of manufacture introduced at the same time so as to fit in better with the new length of spell, may pass entirely unnoticed. In such circumstances results may be attributed to one cause, which are in fact either attributable to that cause in conjunction with another, or entirely to the other cause. For this reason, whenever records are being examined for scientific purposes, and the apparent cause of a certain result is found, every effort should be made to find some other cause or causes which may play a part in the total effect. Even when such interfering factors cannot be found, it should not be assumed that they do not exist, but only that up to the present they have not been discovered. If, in their absence, the solution put forth accounts more satisfactorily for the results than any other that can be suggested, it may be accepted as a definite advance in scientific knowledge, but it cannot be accepted as final and ultimate truth.

When the second method is used, i.e., when a scientific worker makes his own observations and records, further difficulties have to be met, which are not found under laboratory conditions. The actual records themselves we may presume will be carefully and accurately taken, so that the chance of error entering through the unscientific method of taking the records will be reduced to a minimum, but still we cannot expect to find the same conditions in a factory as are to be found in a laboratory. For instance, this method may be employed in the collecting of data dealing with such questions as temperature, ventilation and lighting. When such records are made under laboratory conditions, everything is done to exclude interfering factors and so to get the records as directly comparable as possible. This is impossible in a factory. If records are to be taken of variations in the human organism we cannot be sure that extra-factory circumstances will not alter the conditions of the subjects, and yet, in order that this method may conform to technique, the conditions affecting each subject should be uniform. Similarly, temperature and lighting records can rarely attain to the rigid uniformity that is desirable on account of the exigencies of factory life. Draughts may be present on one day and not on another, and lighting may be affected by many small changes necessitated by the factory routine.

In spite of the many sources of error to which the observational method is open in the study of fatigue, it can be used to very great advantage, and should, in fact, always precede an inquiry of a more specific nature. Its drawbacks we must frankly admit, but in doing so we should not overlook its advantages. By this method a far wider field is covered than is possible in a laboratory investigation, and we are, therefore, often able to detect tendencies which can be more fully examined by other methods, but which would not be detected at all unless the observational method had first been employed. When we use mass data for arriving at special conclusions rather than general tendencies, we are on less sure ground, and such conclusions should rarely be put forward until they have been tested by the experimental method when this is possible.

Experimental Method.

The experimental method in the study of fatigue consists in altering either the *methods* of work or the *conditions* of work, and noting the results. Such experimentation should always be based upon the results obtained by the observational method, otherwise any alteration of method or condition is a leap in the dark ; when, however, it is conducted upon principles already indicated by the observational method, it partakes more of the nature of an intelligent empiricism.

The greatest care must be observed in the use of this method to see that only one change is introduced at a time, for otherwise (if more than one change is introduced at the same time) it will be difficult or impossible to say to what the result is really due. Even when every precaution is taken in this respect, the results may be affected by the feeling of novelty to the operatives, which may affect the results either favourably or unfavourably. In order to overcome this, comparison of results should only be made after a sufficiently long time has elapsed to allow the feeling of novelty to be entirely ineffective. In changing the conditions of works, e.g., altering ventilation, the operatives will often be unconscious that any change has been made that is likely to affect them directly, and so the feeling of novelty is not likely to interfere with the results.

The experimental method is usually a necessary complement to the observational method; for by these means we are able to test conclusions suggested by observation, and so bring them to the touchstone of reality. Workers and employers alike can understand the results of an experiment, whereas they may feel doubt about the somewhat intricate reasoning involved in putting forth conclusions founded upon scientific observation. For this reason alone it should be employed whenever it is possible, for only by enlisting the sympathy and understanding of those engaged in industry can we hope to advance the study of industrial fatigue.

Test Method.

We now come to a method employed in the study of industrial fatigue which is really a combination of the observational and experimental methods, namely, the test method. By this method, groups of individuals are given various mental and physical tests in order to determine their fitness for certain occupations, their liability to accidents or occupational diseases, the nature of their fatiguability, etc. This method is the most difficult of all to apply, and the one about which there is the most controversy; yet it is likely to yield ultimately the most fundamental results, so that a brief consideration of it will not be altogether unprofitable.

To employ the test method satisfactorily, the experimenter must be able to differentiate unambiguously between those persons who possess the particular quality he is testing for and those who do not; or where it is possessed by all, but in varying degrees, he must be able definitely to assign a rank to each person in the group which will really indicate the degree in which the quality is possessed. Very great difficulty is sometimes experienced in securing this differentiation.

Let us suppose that the experimenter is trying to determine some common characteristic possessed by those who are liable to contract an occupational disease or to have industrial accidents, and not possessed by those who are not liable in the same degree. Presumably, he will be able to find a group of persons who have contracted the disease, or who have had an accident, but how is he to be sure that those who, up to the present, appear to be immune are really so, and will not fall a victim later in their industrial career? Various methods can be employed, such as classifying the subjects according to the time they have been exposed to liability; but by doing so we naturally lessen the number of subjects in each class and so reduce the mathematical probability of the conclusions, and in order to overcome this difficulty, so large a number of subjects would have to be tested as to make the experiment quite beyond the resources at present at the disposal of the Board. Further than this, in some cases a disability may be successfully concealed for many years by those suffering from it, and so we can never be sure that we have entirely unmixed groups by any method of classification.

When the test method is being used to detect not liability to disease or accidents, but fitness for occupation, at first sight the matter may appear simpler ; so it is, perhaps, in some degree, but nevertheless it has complications of its own. Proficiency in some occupations can only be judged by foremen or managers, and so will only yield a ranking depending upon personal judgment. However careful those who make such judgment may be, it cannot be expected that they will be entirely free from the sources of error that enter all human judgments, and this incalculable factor may affect, in a degree which cannot be measured, the final correlations of the tests. In occupations where proficiency can be measured by output, the experimenter is on rather surer ground, but even here sources of error may enter which may affect the result. The main cause of such errors is that we cannot be sure if those who possess qualities well adapting them for proficiency in a particular occupation are using these qualities to the fullest extent, and likewise we cannot be sure that those who do not possess such qualities in the same degree are not able to bring to their aid other qualities, let us say of a moral kind, which will do much to cloak their natural unfitness.

Conclusion.

Let us now pass from the sources of error which, strictly speaking, lie outside the control of the experimenter, and consider those that may justly be laid to his account. The only way of formulating tests for a specific object is to base them on *a priori* reasoning from premises yielded by previous observations and experiments ; in other words, to give such tests which, according to our knowledge and previous experience, seem to fit the case best. Unfortunately, this particular branch of science is in so undeveloped a state at present that for many years to come we cannot expect that the tests given will be as accurate and definite as is desirable. A new field is being opened up, and the best methods of exploring it have gradually to be found. Every time the method is employed fresh facts come to light, and new adjustments are made with a view to overcoming errors which had previously escaped notice. It is in this way that the experimental sciences which have developed the test method to so high a degree of perfection have proceeded ; the sciences of chemistry, physics, and medicine, in the early days of their development, each used methods which are now looked upon as entirely inadequate, but those sciences would not have reached their present state of development unless the early workers in them had used such means as they had at their disposal for probing the problems with which they were confronted, in spite of the fact that they were inadequate and were often recognised to be so. We cannot expect that a few experiments will solve such complicated problems as are connected with the reaction of the human mechanism to industrial conditions, nor that we can hastily devise means of deciding questions which up to the present have entirely baffled our understanding.

We are entitled in a young science to demand rigid adherence to scientific method, and if this is not the case it has no right to be ranked as a science; but we are not entitled to demand that it shall adhere to the particular methods employed by sciences dealing with similar but not identical problems. Each science, in order to rank as such, must adhere to the general principles of scientific method; but each science must create its own technique, and the only way in which we can judge such a technique will be if it actually tends to solve the problems it was created to deal with, and not how far it resembles the technique of other sciences. The sciences of industrial psychology and physiology have as their subject matter some of the most elusive factors conceivable, and even if they had reached as full a state of development as the older sciences their conclusions would not pass beyond the stage of probability. Those who are working in them come equipped only with laboratory technique, and their first task is to learn how to adapt such technique to the conditions under which their investigations have to be carried out and at the same time to develop a technique which shall be more adapted for its purpose than one carried over from the laboratory.

The only way to overcome the effect of the various sources of error that have been pointed out, is to avoid adopting conclusions based upon isolated experiments, and to continue experimenting over as wide a field as possible. With the present means at our disposal we cannot expect to arrive at definite conclusions, but only at suggestive ones. The statistical method is of great help in treating the data obtained where it is possible so to do; but this is not always the case. Certain occupations of a non-repetition type do not lend themselves to statistical treatment, but we cannot on that account exclude them. Such occupations may yield information of a definitely scientific nature which only lends itself to treatment on the lines of general inference; this is less satisfactory than it would be if it were possible to employ strictly statistical methods, but it should not be entirely disregarded on that account. Every effort should be made to test the validity of such conclusions by an appeal to the experimental method, for it is often found that conclusions which cannot be substantiated statistically, justify themselves when put into practice.

Even with data which lend themselves definitely to statistical treatment we must avoid laying too much stress on the purely statistical aspect. Naturally, a correlation which is not greater than its probable error cannot be taken into account, but we are not entitled to demand that every correlation worthy of consideration should be sufficiently high by itself to form the basis of a reasonable hypothesis. Correlations which are only just significant should not be too lightly passed over, for they may indicate lines of further research, and in any case, as has already been pointed out, there are sufficient sources of error seriously to mar the method of correlation as a final criterion. It may be possible to repeat the experiment several times, and in each case to eliminate certain sources of error, though in no case to be able to eliminate all. If throughout such a series of experiments a small though significant correlation is found, then we are justified in paying more attention to it than if we evaluated it on a purely mathematical basis, for the probability is that there is a real and important relationship between the two qualities which just manages to make itself felt in spite of adverse conditions.

Conversely, when a correlation is high, we must avoid placing too much reliance on it until it has been submitted to further tests, for it has been found that a test yielding a high correlation with one group of subjects, will not give a significant correlation with another, and apparently similar, group. This tends to show that there are interfering factors which have not been discovered, or that the correlation was not a genuine correlation between the two qualities, but one between one quality and another unknown quality which correlated highly with the quality we thought we were dealing with. It is sometimes possible to overcome this difficulty by the method of partial correlation, but this is not always the case.

Statistical reasoning is a method of determining probabilities. Where the only data at our disposal are of a purely numerical kind, the statistical method is the only means of dealing with them; but in estimating the probability of a conclusion we often have data at our disposal other than the purely mathematical. When this is the case it is highly unscientific to disregard them. If for instance, a rather low correlation has been obtained connecting two qualities, and there are reasons, based perhaps on some independently established principle, for connecting these two qualities, then we are entitled to take this factor into consideration and pay greater respect to the correlation than we should be justified in doing otherwise.

These few instances of methods of overcoming the difficulties which present themselves in the Board's work have been given in order to indicate possible lines on which a technique may be developed that will overcome the difficulties already pointed out, and they must not be taken as in any sense final. It is futile to deplore the existence of the many sources of error that present themselves; it is far better to recognize them and then do everything that is possible to circumvent them. This will be best accomplished, not by slavishly adhering to a technique developed for other purposes, but in going boldly forward experimenting in new methods. Many such experiments will prove to yield no reliable results, but such is the case in all experimental work. There is, however, this difference between experimental work carried out in a laboratory and the type of experiments in which the Board is engaged, namely, that the one is done in private and the other in public; and it is for this reason that it was thought worth while to write this article, in order that those who are interested in the Board's work may be cognisant of its difficulties. The results already obtained from its investigations are sufficient to justify the belief that they are on right lines and that much useful information is to be gained by continuing and developing them. No individual report may be sufficient by itself to establish some general principle, but if the Board's work be taken as a whole, it seems not unreasonable that as time goes on a body of scientific knowledge may be built up which will be of the utmost value to those engaged in industry.

B.—THE USE OF THE SAMPLE IN INVESTIGATION.

By May Smith, M.A.

The relation of industrial fatigue to output is important from two points of view. First, it may be studied primarily with the object of ensuring that human effort is expended in such a way as to secure maximum production. Extensive investigations with this object were in fact carried out by the Health of Munition Workers Committee during the war. Secondly, as throughout the Board's work, output has been used as a measure or test for human variability, and even though in the future other tests should be devised, it is likely to remain the most obvious and on the whole most satisfactory criterion, whether measured in terms of units of work or more indirectly, as in terms of money value. In studying the human factors which affect output, therefore, it is essential that there should be some method whereby that output can be measured.

Measurement by Output.

At the first consideration of the problem it does not seem difficult to conceive of the possibility of measuring output in most occupations ; hour by hour a certain amount of work is done, and to express that amount in such terms as number of articles completed or the amount of money earned would not appear to be an insuperable task. For example, we might estimate in the case of packers how many bottles or boxes or glasses, etc., each person packed each hour of the working day, collect these data for several weeks, and from a study of the results find out what was the normal rate of packing, and when variations about that normal occurred with the object of learning why they occurred. Or we might treat in a similar way hourly earnings where piece rates are worked.

In most of the early fatigue investigations this method was used (the work carried on in munition factories, in particular, lent itself to this treatment), so that by computation of output the variations resulting from days of varying length, etc., could be studied. The extravagance of the 12-hour day for many processes was clearly revealed, and definite evidence was obtained showing not only that the total output resulting therefrom was smaller than from the 10-hour day, but also by how much it was smaller. This method has also been used with undoubted success in determining the advantage of systems of payment, rest pauses and motion study.

It is necessary now to consider the presuppositions which such a method implies. In the first place, it assumes either that the worker is doing precisely the same kind of work every hour of the day and every part of that hour, or that, if at any time his work should vary, it can still all be expressed in the same unit, e.g., a girl employed in polishing spoons might not spend all day at one type of spoon, but it might be possible to translate all the larger spoons into terms of smaller ones. Secondly, it presupposes large numbers of people doing the same kind of work, so that purely individual variations are lost in the mass. If one could show that 1,000 workers working twelve hours a day have a lower output than 1,000 workers working eight hours a day, the chances are that this is true generally, and that on this evidence the 12-hour day is unprofitable. The ideal conditions for the operation of this method then are large numbers of workers employed on work which does not vary throughout the working day. Much munition work was of this character, the worker being occupied most of the working day in repeating the same movements for the production or guidance of the same article. Many other processes of industry, too, are of this nature, and thus lend themselves to direct measurement by the output method.

Some processes, however, and these by no means negligible in number, are of quite a different order ; instead of the regularly recurring cycle of operations, the worker is engaged irregularly in different operations. It is true that the degree of this irregularity varies considerably, but it does exist in many processes, and in so far as it exists it introduces a complicating factor. For example, a worker may have to go to another department at irregular intervals to bring work, or he may be kept waiting at times on a previous process, or he may be employed at one time on one class of work, or at another on something different ; he may have to vary his standard of work to meet requirements of a differing type, his tool or machine may not maintain an unaltering efficiency, some work presents problems which have to be referred to a foreman or another worker. The possibilities of variations in some industries are practically limitless. In such circumstances the computation of hourly output, even where it is possible, will not be of much value, for each hour's output will have been affected by so many variables as to be non-comparable.

To illustrate by one process from one industry—the same workers on a calender (a machine used in laundries for drying and ironing flat articles such as sheets) may be putting through the calender at 8 a.m. sheets of a regular size and type, and they may continue to do so for several hours ; but during the last hour of the period of work they may be putting through towels or workmen's shirts. Obviously, no comparison of output in the ordinary sense of the word can be made.

To show the risk of false conclusions being drawn a further example, taken from an actual investigation, may be given. In attempting to obtain a measurement of output on a calender which was used practically only for sheets, the number put through between 8 a.m. and 9 a.m. was 156, between 10 a.m. and 11 a.m. 147, and this occurred for several days ; investigations revealed, however, that the decrease in the output was only numerical, the sheets done at this particular time being larger in size. To an observer the difference was not striking, and had records been obtained for weeks, still the same result would have been given, because that particular work was always done at certain fixed times.

Consider two such occupations as those of shop assistant or waitress, where the pressure of the work varies for different hours. The number of customers served each hour of the day could give no adequate measure for comparing one hour with another from the point of view of the worker. Suppose that during the last hour of the day she served more customers than during an early morning hour, this could not be interpreted as a sign that her day's work had not fatigued her or that she was less efficient in the morning. It could only mean that she did more work then because there was more work to do ; the measure would be quite inadequate as a measure of personal variation.

The Use of Samples.

In all these non-repetitive processes we are faced with the alternatives either of finding some measure which shall be an adequate symbol of output, or of giving up the problem ; in the latter case our knowledge of the human factors affecting output will have to be limited to repetitive processes, which are but a part of the total number of processes. If, however, we can get some symbol or sample to represent output at various stages, it will give us a practically unlimited field for study ; such a sample will have the drawback of all symbols, namely, it can but represent the reality—it cannot be that reality—nevertheless it may furnish valuable clues. What the sample may be will be determined by each particular process ; the only criterion of its suitability is that it shall be some measure which, obtained for a short period or for a limited number of articles, can be fairly taken to stand for the worker's efficiency over a longer period.

Suppose the problem were to compare various hours of the working day in the case of a telephonist at a large exchange ; if the pressure of the work remained the same all day long, then the usual output method could be adopted and the number of "calls" dealt with each hour calculated. That, however, is not the condition of work. Some periods of the day are much heavier than others ; some calls present special problems, and so on. If, therefore, hourly output is the problem, the ordinary method will fail. In such a case we might concentrate our attention on the periods during the day when the telephonist is working at a normal rate. Then, suppose that the time she takes to deal with 100 calls in immediate succession is measured, that might be a useful measure of efficiency at the moment.

Before deciding, it will be necessary to take several sequences of 100 fairly near to one another, in order to see whether there is a significant variation; if not, then we may feel justified in accepting it as representative of her efficiency at that time. However variable her work may be, it is probable that several hours of the working day will contain periods fairly described as normal; if, then, for such hours we measure the time taken to deal with a fixed number of calls, we shall have a means of measuring that hour's efficiency. It is presumed that all other conditions remain constant.

Such a measure was found useful in working out the hourly efficiency of girls employed in collar work in laundries. A collar, after it has been washed, has to be steamed, polished, curled, etc. Frequently one girl does all or several of the processes, and no one of them can be adequately expressed in terms of the others. Even if, as may happen, one girl is employed in the process of "steaming" all day, yet the collars on which she is engaged will not all be the same; some will be single, some double, some will be new, some torn, some will require special treatment. Actual hourly output, then, will not represent the variation in efficiency, if any. Making allowances for the possible variations, it is true that hundreds of collars present no particular problem, and that during the course of the day the worker will be engaged many times on such collars. The observer, then, can select the type of collar which recurs most frequently, and time with a stop-watch how long the worker takes to "place" 50 collars in immediate succession as nearly as possible every hour. It is easy to determine whether 50 is an adequate number to represent her work. Other conditions remaining constant (and in this respect the sample method is no more likely to be disturbed than the output method), if she consistently takes longer to place 50 collars of one type between 5 p.m. and 6 p.m. than she does between 9 a.m. and 10 a.m., the inference may be drawn that she is feeling the effect of her day's work, and that it is exhibiting itself in a gradual slowing-down process. Whatever may be our interpretation of the falling off, the immediate point is that while the 50 collars are only representative of her total work, they may be a measure of the way in which she is dealing with the whole; if she takes longer at any particular period of the day to do 50 collars, it is a fair assumption that she is taking longer to do the rest of her work. This measure will probably be found to be practicable for all those processes where a worker does work of the same nature all day, but where each article cannot be guaranteed to be strictly the same. This method also has the advantage of allowing for experimental conditions without deranging the work of the factory; those in charge of a department can often arrange for small batches of work of the selected type to occur at times required by the investigator, when the nature of work would preclude all possibility of dealing with large quantities.

Not all processes, however, lend themselves to this type of the sample. Much factory work involves the use of machinery in some form, and the part played by the worker varies between very wide limits. In some operations the physical health of the worker could fluctuate considerably without affecting the particular process, whereas in others very slight variations in health or attention will be reflected in the work. In the former cases the sample as described above might fail to reveal adequately the workers' variations. We have, then, to select the sample from that part of the process which is directly controllable by the worker.

Where series of separate articles or parts of articles are being dealt with, many processes demand that the worker has to take his or her hands off the completed article and take up the next one. This interval may often be the only part of the process which depends on the worker. Selecting the most constant type of work, an investigator might time this interval between a given number of articles and take the average to stand for the efficiency of the work at that particular time.

For example, in calender work, as mentioned above, for reasons which are irrelevant to this discussion, it was deemed inadvisable to measure the time taken to complete a given number of articles; instead, a sequence of time intervals was used, the time being measured from the moment the workers took their hands off the end of one article and placed the next.

Quoting from records actually taken, the following sequences (measured in seconds) were obtained at 8 a.m. :—

3, 4, 4, 3, 4, 3, 4, 3, 4, 3.
$3\frac{1}{2}$, 4, 4, 3, 3, $3\frac{1}{2}$, 4, 3, 4, 3.

The average of the above records is 3·5 seconds, which was taken to represent the work at that time. During a period of several weeks, such records were obtainable for at least five periods of each day and sometimes for nine. This interval proved to be so regular that an average increase of a second challenged investigation. The actual number of intervals selected depended on the type of the work; in the case given above, 20 was found to be convenient and adequate.

The difference in this interval under different conditions is shown in the following examples. For the purpose of simplification, only 10 intervals are given :—

Time, 9 a.m.—
6, 6, 9, 7, 7, 6, 5, 8, 8, 8 seconds.
Mean = 7·0 seconds (extremes, 5 to 9 seconds).

Time, 6 p.m.—
10, 11, 12, 10, 9, 10, 10, 11, 9, 10 seconds.
Mean = 10·2 seconds (extremes, 9 to 12 seconds).

Time, 7.30 p.m. (*Overtime Day*)—
12, 15, 12, 13, 25, 19, 16, 17, 19, 20 seconds.
Mean = 16·8 seconds (extremes, 12 to 25 seconds)

These particular observations apply to one day only and are of no particular value in themselves ; actually, the same type of record was given for over a fortnight. They serve to show that this interval does vary and that it will serve as a useful basis for comparison. It is assumed that the investigator is satisfied that all other conditions are the same throughout ; on all these occasions the workers were quite honestly working hard, and were themselves unconscious of the difference. Quite a number of machine processes would lend themselves to study by this method, but it cannot be fruitfully used where the supply of work is irregular or where laxity of organization allows this interval to be dependent upon other factors.

In still other types of work another form of the sample might have to be utilised, e.g., the time taken to complete a given process a fixed number of times could be found. In laundry work, sheets and table linen, after they have been " calendered," have to be folded ready for packing. It is unlikely that the same two girls will be employed all day in folding the same article, nor are even sheets all of one size and difficulty. Therefore, total output is not feasible. The interval between finishing one and beginning another was found impracticable for various reasons, and because the interval was unreliable, the time taken to do a fixed number could not be used. Instead, the time taken to fold each of 20 sheets in succession was measured and the average calculated, that average being then used as representative of the worker's efficiency at that time. As an example, the following is a record actually obtained :—

Time, 3.30 *p.m.* (*Series of* 20 *sheets*)—

$$\left.\begin{array}{l}15,\ 16,\ 15,\ 16,\ 15,\ 14\tfrac{1}{2},\ 14\tfrac{1}{2},\ 15,\ 16,\ 15\\ 15,\ 17,\ 16\tfrac{1}{2},\ 15,\ 15,\ 14\tfrac{1}{2},\ 15,\ 15,\ 15,\ 15\end{array}\right\}\text{seconds.}$$

$$\text{Mean} = 15\cdot 25 \text{ seconds.}$$

By this method, variations according to the number of hours worked and time of day, as well as individual fluctuation in health, have been revealed.

It must be remembered that many factory processes are with skilled workers firmly fixed habits, and so less easily disturbed than work requiring thought ; also that in these investigations the learner has been omitted, and only expert workers, who have ceased to be affected by practice, studied.

When a process takes longer than a minute a fewer number of articles can be taken as samples, e.g., in using the same method for studying the variations under different conditions of shirt ironing, the sample average was taken from ten shirts in some factories where little was done by the ironers except finish off, and five in factories where more was done. This method in the case of an elderly shirt ironer showed quite clearly the effect of the dinner hour and of a rest in the middle of the morning.

The types of sample given above do not by any means exhaust all the possibilities of samples, but are illustrative of how a part can be utilised to stand for the whole. The method has only been used for a few processes, and very much more work is required to fix its technique and determine the best type of sample to be used. It is here described in the hope that others may find it useful, and in the use of it add to our knowledge of its possibilities and limitations. It is tedious and demands constant watchfulness on the part of the investigator ; and as each record has to be obtained by the investigator personally, much time is required to obtain data. With experience, however, two processes, should they happen to take place within the observer's easy range of vision, can be dealt with together with the aid of two stop watches, and in the course of each hour several processes can be sampled.

The Individual as a Sample.

So far we have discussed only processes as represented by samples ; we must now discuss the worker as a sample. Many factories, instead of employing large numbers of workers on one process, have only a few, and in some cases, perhaps, only one person, on a particular process. For the adequate use of the inductive method, large representative numbers are required ; if, however, these are not available, we are faced with the necessity of studying individuals in the hope of gradually accumulating many (even though the many will not be working under identical conditions if drawn from different factories).

In several of the Board's reports, studies have been given based on one or two workers, and the intelligent critic often, and quite rightly, says that the particular one or two selected may be quite particular, and not representative at all. The intelligent critic, though, must realize factory conditions ; if mass data cannot be obtained there only remain individual data.

Now these individual studies are actually much more representative of large groups than can be shown in reports. Any worker who is in any respect exceptional is well known to the owner or manager, and would most certainly be pointed out as such to an investigator. The oldest inhabitant of a factory, the most juvenile, the worker with a special education or with a special interest in one machine, are not hidden ; more probably they are displayed on a first visit. If not, an investigator is, if sympathetic and tactful, in a specially favoured condition for discovering such peculiarities where they exist. It is a very fair assumption for practical work that large numbers of human beings approximate to a certain type from the point of view of work, and in a factory the chances are that one or two workers on a process are fairly representative of quite large numbers who would be engaged on that process. If a worker were in any respect (from the point of view of the work) unique, then, except as an individual, no investigator would concern himself with that worker. Suppose, however, that a study has been made of the hourly variations of a particular worker, and that that study is given as a sample of that process, the conclusion implicit in the writer's mind is not that from his study of one worker he is in a position to assert confidently that one million workers will each behave in identical fashion, but that from a study of this apparently normal worker he would expect other workers in such a position to behave similarly, and that the result is a hint for further study.

Further studies in other factories doing the same work will either substantiate or invalidate the original study. Time alone can determine which. It is significant that already, where further results are available, these individual studies usually receive support. Where different investigators working on different lines in different trades, and ignorant of the results of one another's work, obtain similar results, the chance of each being true only of the individual concerned is much reduced.

From some points of view individual studies are even more valuable than mass data, where necessarily the individual variations are masked, for just as it is important to know how workers in general behave, so also is it important to know how particular workers behave. We are a long way yet in this work from being able to generalize ; we can but say that within the limits of each study such and such sequences seem to be in relation. That, however, in itself is useful, and only future study can determine whether a sequence regularly observed is related as cause and effect, or whether the two are really the expression of some remoter cause. A sequence once shown to happen in individual cases will be considered and studied more frequently in other cases, and so in time it will be possible for valid generalizations to be drawn.

" Though so little use can be made in science of approximate generalizations, except as a stage on the road to something better, for practical guidance they are often all we have to rely on."* Much of the Board's work at this stage must be of the nature of " approximate generalizations," which, however, we may legitimately hope to be " stages on the road " to more conclusive evidence. With the advance of interest in this work more reliable records will be available in the various industries, but individual study will always have to be a part, for it is the individual who works, even if 1,000 are employed on one process.

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* J. S. Mill, *System of Logic,* XXIII.

C.—SOME OBSERVATIONS ON INDUSTRIAL CONDITIONS, WITH SPECIAL REFERENCE TO COTTON WEAVING.

By S. WYATT, M.Sc.

The history of the cotton industry provides an interesting illustration of the manner in which attention tends to be focussed almost exclusively on the mechanical and physical factors necessary for efficient production, and the effect of these factors on the human element has been largely ignored. It has been usually assumed that the human mechanism is able to adapt itself to industrial conditions, and although this is fortunately true within limits, a point is sometimes reached when further adaptability is no longer possible and the conditions become physiologically harmful. The centre of gravity is now, however, gradually tending to move in the direction of the worker, and instead of his being compelled to adapt himself to the unsuitable design of the machine, unusual atmospheric conditions, and unfavourable methods and conditions of work, these different objective factors are being brought into greater harmony with his natural ability and requirements.

The reports of the Industrial Fatigue Research Board, dealing with the weaving section of the industry, have been for the most part of the nature of general surveys, but they have disclosed many points on which further special investigation on systematic lines is clearly needed. These are briefly set out in the following pages, and it is hoped that some machinery for dealing with their study may be set up within the industry itself.

Temperature and Humidity.

In many weaving sheds the atmosphere is both hot and moist, and the conditions often reach a point when discomfort results. It has, for instance, been shown that as the wet-bulb rises, so does the body temperature of the operatives, and that this effect is very marked when the wet-bulb reaches about 75° F.

Under existing conditions, the number of yarn breakages in humid sheds decreases and efficiency increases up to a temperature of approximately 75° F. and a relative humidity of 80 per cent. Beyond this point the number of yarn breakages may continue to decrease, but the efficiency remains the same, or may even decrease, because of the unfavourable effect of the hot moist atmospheres upon the working capacity of the operatives. * In an industry in which efficiency depends so much upon atmospheric conditions, the determination of the most suitable temperature and humidity for each kind of yarn seems to be a prime necessity, yet this problem still awaits solution. Breakage tests upon different warps exposed to varying atmospheric conditions are urgently needed. Once the most suitable conditions have been determined, the next step is to reproduce and maintain them in the shed throughout the working day, and an apparatus

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* Report No. 23 of the Industrial Fatigue Research Board.

which is said to be capable of doing this is now on the market. At the present time fluctuations in temperature and humidity are comparatively large and the optimum conditions are only occasional and transitory.

Again, since atmospheric conditions which are most suitable for the yarn are unsuitable for the weavers, the yarn must be exposed to a different atmosphere from that which surrounds the weaver if a higher efficiency is to be attained. In other words, some system of local humidification must be adopted, and the few experiments which have been made along these lines appear capable of further development.

Lastly, the possibility of increasing the rate of air movement in weaving sheds and thereby providing more invigorating conditions for the operatives, seems to have received very little attention. Such a procedure appears to be one of the few ways by which the high temperature and humidity necessary for the manufacture of the yarn can be maintained and their unfavourable effects upon the operatives at the same time decreased. Some results along these lines have already been obtained,* but additional experiments are very desirable.

Lighting.

Industrial lighting is a subject which has long attracted the attention of illuminating engineers, with the result that the lighting in many industrial establishments is now highly efficient. In some of the older works, however, the managements have failed to keep pace with scientific discoveries in this field, and antiquated and defective installations still exist. Thus, several firms in the cotton industry use incandescent gas mantles of antiquated type as the source of illumination. During the summer months the mantles are usually broken or removed from their fittings, with the result that the shed is in a state of partial darkness on dull days, and the decrease in efficiency at such times must be very significant. In other cases, the lighting system, although modern and adequate in many respects, is often capable of improvement in others. In weaving sheds, for instance, the position of the sources often gives rise to glare and causes shadows in undesirable places, and such conditions are well known to be a contributing cause of eye-strain and fatigue. Recent investigations have also shown the relation between output and illumination, and the dependence of accidents upon inadequate illumination has also been established. Further, there is clearly no uniform opinion as to the lighting requirements in weaving, since the candle-power of the light sources and the number of looms per source vary in different sheds, and some systematic inquiry on this point seems to be desirable.

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* Report No. 21 of the Industrial Fatigue Research Board.

The nature and amount of illumination not only has economic and hygienic effects, but operates psychologically upon the operatives. The difference between the bright and cheerful disposition of a person on a sunny day and his attitude on a dull grey day is often most marked. A similar difference is noticeable between the inhabitants of sub-tropical climates and those of colder lands. In the same way, the contrast between the depressing effects of a dark workroom and the bright and cheerful atmosphere of a well-illuminated factory are obvious to everyone. The effect of different colours upon the feelings is not so noticeable, but it exists nevertheless. Colours, frequently produce definite reactions, and their direct and associative influences cannot be long ignored, though experiments have not yet revealed the exact effect of various colours upon the feelings and mentality of an individual. Thus, light and colour tend to promote cheerfulness and dispel gloom, and a cheerful nature is an important factor in the preservation of bodily health.

Industrial operations are often conducted in somewhat dismal surroundings which might be improved. A weaving shed is a hot and noisy room with whitewashed walls, and "saw-toothed" roof supported by dismal-looking pillars, and containing a collection of dull black looms. A great relief is experienced when one happens to enter a shed in which coloured fabrics are woven. White walls are considered necessary, because of their reflecting power, but there seems to be no reason why the looms should not be painted a pleasant green and the pillars made pleasing as well as useful.

Noise.

Noise is a feature of many industrial processes which has received relatively little consideration. It is a striking characteristic of all weaving sheds, and the amount of energy wasted in producing the noise must be very great. The operatives and employers look upon noise as an unavoidable part of the process of manufacture, and assert that they become adapted to it and are accordingly unaffected by it Probably, under normal conditions of health the workers are not appreciably affected by the noisy environment, but as soon as they become "run down" the noise becomes distinctly irritating and disturbing. Piano-practice by a neighbour, for instance, may be tolerated by one in good health, but when one is "off colour" may become unbearable. Similarly, when sickness prevails in a house, devices are often used to render the outside traffic noiseless.

It appears probable that the nervous system is attuned to the conditions represented by a normal environment, and the presence of an additional stimulus, such as noise, makes an additional demand upon the nervous system. The amount of strain a person can bear is limited, and in cases of indisposition, this limit is considerably decreased. Noise is objectionable chiefly because of its effect upon attention. Voluntary attention is a selective process, and the effort to attend is increased by a distracting stimulus such as noise. This opens up the difficult problem whether the industrial worker, although apparently oblivious to noise, may not be using up energy in maintaining that state of oblivion ; if so, noise is not a negative and negligible factor in life, but can be discounted only by the expenditure of effort, and the energy required for this purpose might have been available for productive purposes.

The actual effect of noise on working capacity has not yet been fully investigated. The interfering effect of noise may, perhaps, depend upon the kind of activity being performed. In the case of automatic mental or muscular work the disturbance will be relatively small, but in processes requiring a high degree of thought and concentration the effect will be much greater. In cotton weaving the work is by no means automatic, and the invention of a silent loom would be a boon to everyone connected with the manufacturing process. In the meantime, experiments on the effects of noise are desirable, and some operation should be selected in which the same operatives could be tested and compared under both quiet and noisy conditions.

Selection.

The selection of workers for special tasks is based upon the existence of individual differences in working capacity. Everyone is familiar with physical differences, such as height or hair colour, but mental differences are not so obvious. Physical considerations are of primary importance in the selection of men for training as a jockey or boxer, but the importance of mental, muscular and temperamental qualifications in industrial occupations is insufficiently recognised. Individual differences in ability exist in all industries, but the expression of these differences depends to a large extent upon the type of industrial process. In the cotton industry, for instance, it has been shown[‡] that in the highly automatic process of spinning, individual differences in efficiency are exceedingly small, because of the overwhelming effect of the mechanical factor. In a less automatic process, such as weaving, however, efficiency depends to a greater extent upon the suitability of the operative for the work, because the duration of loom stoppages is largely a personal factor. In another investigation[§] it was found that the efficiency of operatives engaged in weaving the same class of cloth varied from 70·2 to 92·6 per cent. In the silk industry Elton has shown that in the case of 32 weavers working under similar conditions.

[‡] Report No. 7 of the Industrial Fatigue Research Board.
[§] Report No. 23 of the Industrial Fatigue Research Board.

their efficiencies varied from 55·0 to 82·2 per cent. on one class of cloth, and from 41·5 to 70·6 per cent. on another.‡

Such differences are very significant, and since the objective conditions were approximately the same in each related series, it follows that the differences must have a subjective origin. A writer has stated§ that "the major portion of the individual differences in the output of cotton workers is a measure of their individual competence for the task." This is undoubtedly true, and it accordingly appears that the general efficiency of the industry would be considerably increased by the selection of suitable operatives for the work. Incompetence frequently leads to dissatisfaction and tends to increase labour turnover, as the incapable operative sooner or later migrates until she finds an occupation suited to her abilities. Further, the inefficient worker usually expends more effort and consequently becomes more fatigued than one who is able to do the work with ease. It is accordingly advantageous to the employer and the operative if the latter is able to follow the occupation most suited to her abilities and desires.

In the weaving section of the cotton industry an attempt has been made to observe the chief capacities necessary for efficient weaving. A weaver is usually in charge of four looms, and loom stoppages occur at irregular intervals; also, while attending to a breakage on one loom, the weaver has to keep an eye on the other looms, and in the case of simultaneous stoppages she must decide which loom should have immediate attention, in order that the total duration of the stoppages may be reduced to a minimum. Hence, the possession of a high degree of distributive attention, together with the ability to form a quick and accurate judgment were thought to be important factors in weaving efficiency. A good weaver also excels in the ability to anticipate stoppages, and the work provides many opportunities for the expression of this capacity. Skill and dexterity in repairing yarn breakages also form part of an efficient weaver's equipment, although these abilities do not appear to be as important as those previously mentioned. In addition, a certain amount of general "intelligence," as well as specific aptitudes, seems to be an important ingredient in weaving ability. Elton, in an analysis of the abilities required in silk weaving, concludes* that "productivity in weaving depends to some extent on the speed with which the weaver performs certain standard operations, and to a greater extent on the methods which the weaver adopts." Thus, the chief capacities involved in weaving appear to be :—

(1) Distributive attention.
(2) Quick and accurate judgment.
(3) Ability to anticipate stoppages.
(4) Manual skill and dexterity.
(5) General intelligence.

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‡ Report No. 17 of the Industrial Fatigue Research Board, p. 12.

§ "The Textile Manufacturer," September 15th, 1920.

* Report No. 17 of the Industrial Fatigue Research Board.

Having determined what appear to be the most important abilities necessary for successful weaving, the next step is to construct tests, in accordance with psychological principles, involving these capacities. The tests should then be given to a number of weavers employed in the same shed, and the results obtained compared with the actual weaving efficiency of the operatives. The greater the degree of resemblance between the results of each test and weaving efficiency, the better is the test as an index of the capacities required in successful weaving. When tests have been obtained which give results fairly similar to the operative's known efficiency as a weaver, they may be considered suitable for application to young people who desire to become weavers. At this stage, candidates should not be retained or rejected on the basis of the test results, but should be admitted as beginners and their progress followed until they become experienced weavers. Their efficiency as weavers can then be compared with their previous test results, and if it is found that a fairly close agreement exists, the tests may be considered satisfactory and used for actual selection purposes. Not until the tests have been thoroughly tested and repeatedly checked should they be applied in practice. Years must elapse before satisfactory standardised tests can be *applied* to the selection of workers for an industrial process.

Training.

The logical sequel to the selection of operatives according to their general suitability for a particular task is to train them in the best methods of work. Recent research* has shown that operatives left to themselves adopt widely different methods in performing the same operation, and although it is highly improbable that any single method is the best for all workers, the great variations in the uncontrolled movements of different operatives indicate that they are not working along the most methodical and economical lines. Before the training of operatives can be carried out, the essential and most suitable movements involved in the work must be determined. This can be done by a detailed and accurate time and motion study which enables a complete analysis of the motions to be made. By these means all unnecessary and unduly fatiguing movements are eliminated, and only those motions retained which appear to conform to physiological laws. As the result a new set of movements is devised, which usually represent the easiest and quickest method of performing the task. Operatives are then instructed in the new method of work, and here the fact must be emphasized that an efficient worker is not necessarily a good instructor. In most industries, the necessary knowledge is acquired in an informal manner after long experience. Experience is an excellent teacher, but is often long and costly. It is only obtained as the result of numerous but irregular repetitions of different situations. An organized system of instruction arranges and controls the occurrence of the necessary situations, and provides a person capable of pointing out the best method of dealing with them. When one remembers the amount of time, money, and energy devoted to the training of athletes, and of the puny and insignificant efforts directed to the training of operatives, the contrast provides food for reflection.

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* Reports Nos. 14, 15, and 17 of the Industrial Fatigue Research Board.

In cotton weaving it has been common, until recently, for a child to start work at the age of 12 or 13, while she is still at school for half the time. After a little preliminary experience, she becomes an assistant or tenter to an experienced weaver and her rate of progress depends largely upon the attitude of the weaver. Some are impatient and refuse to allow the tenters to touch the loom, with the result that their experience does not extend beyond shuttle filling. The more conscientious weavers, however, take a pride in advancing their tenters from one operation to another until they are capable of managing a loom. A considerable time elapses before a tenter is able to attend to warp breakages, and she will probably never be allowed to put in the headings and repair flaws and floats in the cloth. The usual tenting period is about eighteen months, but there is no fixed rule and the time depends upon the general aptitude of the child and the opportunities for promotion. At the end of the tenting period, the young weaver is given two looms usually in the neighbourhood of her former teacher, who still watches over her and helps in cases of serious difficulty. When considered sufficiently skilled she is given an additional loom, providing one is available. A number of the young weavers find the strain of controlling two looms too great and frequently leave at this stage. There is no system by which the overlooker decides that a child is unsuited for weaving except by her inability to earn the minimum wage fixed by the firm. Thus a considerable time elapses before a weaver definitely proves herself incapable. This is one of the chief drawbacks of the system, and provides a strong argument in favour of the selection of operatives by psychological tests. The informal and promiscuous method of training is also unsatisfactory, and managers who have appointed separate instructors for this purpose speak highly of the results obtained. Not until young operatives are taught along systematic lines by capable instructors will the stage of maximum efficiency be approached.

Some of the more advanced firms in the cotton industry have recently introduced definite training schemes. In one firm, for instance, a small shed containing about 30 looms has been set up for this purpose. Beginners are first instructed in an adjoining room containing two looms, desks, and a blackboard. Here the foreman introduces the prospective weaver to the loom and deals with the nature, causes, and method of treatment of the various kinds of stoppages encountered in weaving. The young weavers then pass into the instruction shed where they are taught to weave by experienced weavers, who are also capable instructors. At the end of about three months they are allowed to take charge of two or three looms in one of the sheds or become assistants to a six-loom weaver. The foreman is usually able to tell at the end of the first week's instruction whether the girls possess the abilities and temperament necessary for successful weaving, and those who appear to dislike the work, or obviously lack the essential abilities, are discharged. A training scheme such as this has been found invaluable, and not only promotes efficiency and economy, but also trains the weaver in the special kinds of work done in the sheds.

Monotony.

In recent years industry has developed along the lines of increasing specialization and standardization. The numerous and varied activities formerly performed by one worker are now distributed amongst many, and this subdivision of labour has greatly increased the amount of routine and repetition work, with a consequent increase in monotony. Other things being equal, the more repetitive and automatic the industrial activity, the greater the associated monotony. Inquiries have revealed the fact that a type of individual exists who prefers this kind of work, and dislikes operations involving thought and responsibility. Such a person allows his mind to wander, or " day-dreams " during the greater part of the working hours. This state may ultimately impair the mental health of the individual since it tends to lead to an undesirable form of mental dissociation. In any case the state of mental inertia developed by such industrial conditions will probably affect the mode of life outside the factory, and it is conceivable that the contributions of such a person to national thought and social progress will be insignificant or even negative.

The existence of individuals who not only tolerate but find pleasure in repetition work may possibly be due in some degree to our educational system. There are, of course, many people who endure repetition work for a time, but sooner or later the monotony of the task makes them seek relief elsewhere. It is undoubtedly true that the general mental constitution of the worker determines the amount of monotony associated with an industrial activity, since the same operation has very different effects, from the standpoint of monotony, on different people. In this connection it has been suggested that the liability of an individual to suffer from the effects of monotony should be taken into consideration in the selection of workers for industrial tasks.

Apart from these subjective considerations, however, the objective aspects of industrial conditions are tending to increase the monotony of industrial life, and one of the most important questions in the near future will be the possibility of alleviating the monotony produced by work. Some industrial leaders are in favour of the day being divided into two shifts of six hours each, as a means of decreasing the cost of production. This arrangement would, at the same time, reduce the period of exposure to conditions which are conducive to monotony and give more time for leisure and the development of other interests. Interest in work increases, and monotony accordingly diminishes, when the work is a means to a desired and pleasurable end. Thus, for some time prior to the annual holidays, the work may acquire a derived interest from the anticipated pleasures, and a task, which in itself is dull, may lose its monotony when associated with the realization of a desire. The masses of figures in a railway time-table are uninteresting in themselves, but when used in connection with a holiday, they acquire an unusual attraction. The possibility of decreasing monotony by creating a derived interest in work is worthy of more consideration.

In cotton weaving the effects of monotony are not so noticeable as in many other industrial occupations. This is chiefly because yarn breakages occur at irregular intervals and are varied in character. The element of uncertainty thus introduced, together with variation in the method of treatment, tends to retard the onset of monotony. In fancy weaving the tendency for the work to become monotonous is still further reduced by the gradual development of the pattern, which is usually a source of interest to the worker. The interest of a weaver in his work is also increased when he possesses a knowledge of the loom and the mechanism of its component parts. The courses of instruction in weaving conducted in several industrial centres do much to increase the interest in the process of production. As one speaker* has said : " Suppose a man went down to his lathe in the morning, with a real understanding of metallurgy and mechanics, and an intelligent appreciation of the scientific principles underlying his work. Would he still find it monotonous and dull ? It is not repetition, but meaningless repetition that kills."

In a similar manner, interest could be stimulated by lectures† or the distribution of pamphlets giving the evolution of the weaving industry and the destination and uses of the various cloths manufactured. The history of the weaving industry is a fascinating document, and the process of converting yarn into such cloths as dhooties for turbans and loin cloths is equally interesting. The use of the suggestion box also is not to be despised, for when properly used it induces the worker to think about possible improvements when otherwise his mind would be inactive and dull. Enterprising employers are beginning to realize that the welfare of the worker is worthy of more consideration and are endeavouring to improve the health of mind, as well as of body.

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* Major L. F. Urwick, at a Lecture Conference, Oxford, 1921.

† In this connexion the following extract from " Labour Policy—False and True " (Sir Lynden Macassey) is interesting :—" One of the expedients to which the Department of Shipyard Labour resorted was the institution of talks with workmen in various ship-repairing districts of the roles being played in the stirring circumstances of the times by naval and merchant ships, which were in dry dock in local shipyards for reconditioning or repair. It had a most stimulating effect ; men found themselves no longer sluggishly working upon an uninspiring metal hulk, but upon a living ship redolent with stirring associations, engaged in performing for the nation functions and duties which they could readily understand. There was less time lost, less sleeping on night-work, fewer stoppages of work, greater expedition, and larger output." (p. 212.)

Investigations on the behaviour of the human element in industry are still in their infacy, but the results already obtained illustrate their importance. On the mechanical and technical sides the applications of science have resulted in remarkable developments, but the human aspects have received very little consideration. The interactions of every part of the machine and the laws controlling them are thoroughly understood, and attempts to increase efficiency are always being made. If the machine runs badly or breaks down, the possible causes are explored and the defects remedied. The human organism, however, has received comparatively little attention and is seldom considered. Although it also works according to definite laws and reacts differently to varying conditions, it is left to overcome obstacles and to adapt itself to difficulties as best it can. Such important questions as the design of the machine, the relation between its speed and rhythm and the working capacity of the operatives, are left largely to chance, and although the height, reach, and rate of working of the operatives vary considerably, the machines are all cast in the same mould. The delicate and intricate mechanism of the human machine is infinitely more wonderful than the creations of man, and although it conforms to definite physiological and psychological laws, very few attempts are made to provide the conditions which will enable it to function most efficiently. The possibilities of applying scientific methods to an investigation of the human element in industry is only just beginning to receive recognition, and a wide and promising field of work is awaiting investigation.

D.—ATMOSPHERIC CONDITIONS AND INDUSTRIAL EFFICIENCY.

By H. M. Vernon, M.D.

Introduction.

It has long been known that industrial efficiency is to some extent affected by the atmospheric conditions under which industries are carried on ; but as the result of investigations made during the last few years, we are gradually coming to realise that the effect is much greater than was previously supposed. The information at our disposal is still very incomplete, so it is to be hoped that increased effort will be made in the future to investigate the subject thoroughly. The results already attained indicate that much can be done to improve adverse conditions, and, moreover, that the expense of improvements will be more than counterbalanced by the increased efficiency of the workers. Hence, we trust that our manufacturers may be induced to give their whole-hearted support, not only to further investigation and research, but to the remedial measures which such inquiries suggest.

The Effect of Atmospheric Conditions on Efficiency in Weaving.

In the weaving of certain qualities of linen and cotton goods, it is the universal custom to carry out the process in artificially humidified air at a high temperature. Experiments recorded in the Report of the Departmental Committee on Humidity and Ventilation in Flax Spinning and Linen Weaving Factories,* show that the higher the temperature and the greater the humidity the fewer are the breakages of warp threads, and the greater the amount of cloth woven in a given time. This is well shown by the average results recorded in the table. The "Time occupied" represents the number of minutes required to weave unit length of cloth.

Weaving of Fine Cambrics.

On basis of temperature.				On basis of difference between dry and wet bulb temperatures.			
Wet bulb temperature. (° Fahr.)	Difference between dry and wet bulb (° Fahr.)	Warp breakages.	Time occupied	Wet bulb temperature (° Fahr.)	Difference between dry and wet bulb (° Fahr.)	Warp breakages.	Time occupied.
61·6	1·5	11·3	52·0	66·0	**1·1**	6·3	47·5
64·0	1·7	11·1	54·0	66·0	**1·4**	7·4	45·4
65·7	1·5	7·3	47·6	67·0	**1·6**	6·8	46·1
68·5	1·6	7·6	46·0	64·6	**1·7**	9·8	50·2
72·0	1·7	6·3	42·0	68·0	**2·2**	13·3	60·0

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* Cd. 7433, 1914, p. 103.

It is obvious that high temperature and humidity, though they improve the physical qualities of the linen thread woven, diminish the comfort of the weavers in proportion to their magnitude, and may indeed affect their health. Consequently, regulations were recommended* which required a difference of at least 2° F. between the wet and dry bulb temperatures, and debarred the manufacturers from artificially humidifying the air when the wet bulb temperature reached 80° F. The average results obtained in a number of sheds showed that in summer time the wet bulb temperature exceeded 70° for about 60 per cent. of the total hours worked ; exceeded 75° for 30 per cent. of the time, and exceeded 80° for 5 per cent. of the time. Moreover, in the Irish cambric factories the permissible difference of only 2° between wet and dry bulb temperatures was usually kept to, so the atmospheric conditions must have been very trying to the weavers.

It is important for us to ascertain if the conditions were so trying as to affect health and efficiency. I know of no exact evidence on the former point, but on the latter valuable evidence has been adduced by H. C. Weston, in the Report to the Board (No. 20), summarised on another page (p. 81). The two sheds investigated by him had a practically constant humidity corresponding to 88 per cent. saturation during the period of the inquiry, and it was found that, as a rule, the output varied proportionately with the wet bulb temperature. Taking the maximum output as 100 (for looms running continuously), the usual efficiency was about 60, and it rose or fell roughly 1 per cent. for each rise or fall of 1° in wet bulb temperature. Above a wet bulb temperature of 75°, however, the output fell rather than rose with increasing temperature. For instance, on the afternoons of three consecutive days the temperature in one shed averaged 74·1°, 75·6° and 74·8°, and the efficiency was, respectively, 3·3, 1·8 and 1·6 per cent. less than in the morning, when the temperature averaged 68·9°, 69·0° and 69·3°. This was the immediate effect of the high temperature on the productive capacity of the weavers, but there appeared to have been a deferred effect as well, as a night's rest did not enable the weavers to recuperate completely after they had been subjected to such trying conditions. Thus, on the second of the three days in question the efficiency averaged 0·8 per cent. less than on the first day, and on the third day it averaged 1·3 per cent. less.

The question arises as to whether it is not possible to maintain atmospheric conditions compatible with a high degree of efficiency so far as concerns the physical requirements of weaving, but without any appreciable effect on the energy of the weavers. Recent laboratory investigations suggest a solution of the difficulty, though it will be necessary to extend these investigations to the weaving sheds before the problem is really solved. The unpleasant effects of hot and humid air depend on the fact that the normal loss of heat from the body is retarded, but such loss can readily be increased (*a*) by diminishing the amount of clothing, and (*b*) by increasing the velocity of the air currents moving against the body. The clothing of the weavers is a personal matter, and it is probable that they frequently, if not generally, wear too many clothes when at work. It would be best for them to change their clothes completely for thin garments on arrival at the mill, but as far as I am aware, this is very seldom done, and, indeed, there are usually no facilities for it.

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* Cd. 7433, 1914, p. 24.

The strength of the air currents, and their cooling effect on the body, can best be investigated by means of the kata thermometer, an instrument invented by Leonard Hill. The rate of cooling of this thermometer from 100° F. to 95° F., or at what is approximately body temperature, is determined (*a*) when the bulb is dry, and (*b*) when it is covered with wet muslin. The former rate depends on two factors conjointly, viz., the temperature of the surrounding air and the velocity with which the air currents are moving against the bulb. These factors are mutually compensatory ; for instance, in order that the air may have a cooling power of 6, it may have a temperature of 65° (dry bulb) and a velocity of 21 ft. per minute, a temperature of 75° and a velocity of 94 ft., or a temperature of 85° and a velocity of 455 ft. per minute. In the wet kata thermometer a third factor comes in, viz., the cooling produced by the evaporation of water from the surface of the bulb. This usually has a much more marked cooling effect than either of the other factors, and Hill considers that whilst a fairly well ventilated workshop ought to have a dry kata cooling power of at least 6, its wet kata cooling power should be 18. That is to say, 18 — 6 = 12 units of the cooling power should be due to the evaporation of moisture.

Weston made a few observations on the cooling power of the air in linen weaving sheds, and he found that when the dry bulb temperature varied from 68·2° to 71·9°, the dry kata cooling power varied from 5·6 to 4·9, and the wet kata cooling power from 15·5 to 14·1. Probably these values are higher than those usually met with, for Wyatt, who made a large number of observations in humid cotton weaving sheds, found that in summertime the dry kata cooling power varied from 3·8 to 4·7, and the wet kata cooling power from 12·0 to 14·2. In any case the values observed are considerably lower than the very moderate standards suggested by Hill, and the question is, how can they be most easily and conveniently raised ? The air velocities, as calculated from Weston's figures, correspond to 25 ft. per minute, whilst Wyatt's figures show a mean air velocity of 26 ft. per minute, both in summer and winter. These velocities are much too low, for Hambly and Bedford, in their observations on the atmospheric conditions in 35 boot and shoe factories, found a mean velocity of 35 ft. per minute in the winter and 37 ft. in the summer. Very few of the boot and shoe factories were overheated at any time, so a comparatively low air velocity would not have mattered much ; but most of the weaving sheds were overheated all the year round, and this overheating should have been compensated for by an extra amount of air movement.

Though we have not yet got sufficient information to enable us to fix exactly what dry and wet kata cooling powers ought to be maintained in weaving sheds, we can safely say that in the past they have as a rule been too low in winter-time and considerably too low in summer-time. Hence, the amount of air movement ought to be increased in humid linen and cotton weaving sheds, with few, if any, exceptions. The manufacturers, on their part, may maintain that increased ventilation tends to dry the yarn and cause increased breakages. It seems improbable that this would happen to more than a very limited extent in linen weaving sheds if the difference between the wet and dry bulb temperatures were only 2°, but if it did so, it might be better to relax the regulation about the temperature difference and impose a new one to the effect that the velocity of the air currents must be above a certain agreed figure.

The existence of an interval of 2° between the wet and dry bulb temperatures is useful, as it helps to keep the clothes from getting damp by the deposition of moisture from the air ; but it must not be taken to indicate that if the temperatures were the same, i.e., if the air was absolutely saturated with moisture, all cooling of the skin surface by the evaporation of moisture would be prevented. The temperature of the skin is usually only a few degrees below that of the body, which is 98·6°, and therefore perspiration evaporates at a rapid rate in absolutely saturated air, until this reaches a temperature of over 90°. Indirect proof of this fact was obtained by kata thermometer observations. I recently made some hundreds of observations of the rate of cooling (*a*) in air 50 to 70 per cent. saturated with moisture, and (*b*) in air about 95 per cent. saturated.* The experiments were made at temperatures ranging from 60° to 100°, the air velocity being in every case about 40 ft. per minute. The average results showed that, e.g., in relatively dry air with a wet bulb temperature of 70° and a dry bulb of 77·6°, the wet kata cooling power was 16·5 and the dry kata cooling power was 3·9. Hence, the loss of heat from evaporation was $16{\cdot}5 - 3{\cdot}9 = 12{\cdot}6$. In moist air with a wet bulb of 70·0° and a dry bulb of 70·9°, the kata cooling powers were 16·3 and 5·8 respectively, so the loss of heat from evaporation was 10·5, or only 17 per cent. less than in the relatively dry air. It can be calculated that if the air had been absolutely saturated with moisture the loss from evaporation would have been about 19 per cent. less than in the dry air, whilst it would have been 14 per cent. less if the dry bulb temperature had been the regulation 2° above the wet bulb. The cooling kata thermometer, however, differs so considerably from the cooling human body, covered as it is with clothes, that no strict comparison is possible. In order to render the conditions of cooling more similar, I made other series of experiments in which the kata thermometer, both dry and wet, was allowed to cool with its bulb in a small cage surrounded by flannel. This caused its cooling rate to be twice as slow as before, but the loss of heat from evaporation when the thermometer was in moist air approached even more closely to its loss when in dry air than in the above recorded experiments. The reasons for this are discussed in the report.

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* cf. The Kata-thermometer in Studies of Body Heat and Efficiency. *Medical Research Council, Special Report No.* 73.

As the kata thermometer observations appear to indicate that the loss of heat by evaporation of moisture is not greatly diminished in moist air, it may be wondered why it is that some of the weavers object so strongly to artificial humidification. Thus, when a ballot of the weavers at Blackburn was taken in 1906, 68,154 voted for the abolition of " steaming," 3,094 voted against it, and 1,221 were neutral. Probably the chief reason is that in humidified air the perspiration tends to collect on the skin and damp the clothing. If, as is often the case, the clothing worn is too heavy, and is not changed directly after work, this leads to considerable discomfort. Such discomfort could be largely overcome if the workers changed their clothes regularly before and after work.

It was shown by Haldane that the maximum temperature which can be borne for some hours without the development of heat stroke, depends only on the wet bulb temperature and not at all on the dry bulb temperature or the humidity. It is probable that the weavers likewise suffer from high wet bulb temperatures rather than from high degrees of humidity, and that future regulations of the linen and cotton industries ought to be concerned with questions of wet bulb temperature and of cooling power, and not of humidity. It is stated* that medical evidence indicates that bodily discomfort begins at approximately 70° wet bulb. This temperature, coupled with one of 72° dry bulb, gives a dry kata cooling power of 5·0, if the air velocity be 28 ft. per minute. Supposing that this cooling power be accepted as the minimum permissible, then it would be necessary to increase the air velocity to the following figures when the wet bulb temperature was raised to 75° and 80°.

Dry Bulb Temperature.	Wet Bulb Temperature.	Dry Kata Cooling Power.	Air Velocity per minute.
72° F.	70° F.	5·0	28 ft.
77°	75°	5·0	68 ft.
82°	80°	5·0	173 ft.

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* Report on Humidity and Ventilation in Cotton Weaving Sheds, Cd. 5566, 1911, p. xxix.

The weaving of cotton does not appear to be so sensitive to temperature and humidity as the weaving of linen, for Wyatt found that in some sheds there was no appreciable increase of production with rise of temperature, though there was a moderate one in other sheds. He found that the humid sheds had an average wet-bulb temperature of 66° in winter and one of 70° in summer, the dry-bulb temperature being about 4° higher in each case. The regulations allow a minimum difference of 2° between wet and dry bulb temperatures at (wet-bulb) temperatures of 68° or less, but at 70° the difference must be 3°, and at 75° it must be 5°. Hence the conditions are not so trying as in linen weaving, although they are certainly capable of improvement. If increased ventilation be found to have a serious influence on the quality and quantity of the cloth woven, it is probable that the difficulty can be overcome by instituting some system of local ventilation. Wyatt found that if a 3-in. strip of canvas were attached to the heald roller of the loom, so as to act as a kind of punkah, the dry kata cooling power of the air in the vicinity of the weaver was increased from 4·6 to 9·0 (corresponding to an increase in air velocity from 21 ft. per minute to 252 ft.), and the wet kata power from 13·4 to 25·9. The air had a wet-bulb temperature of 68·5°, so it is evident that even if it had been considerably hotter, its cooling power would have been well above the recognized standard.

The Effect of Atmospheric Conditions on Efficiency in Deep Mining.

High as are the temperatures sometimes experienced in weaving sheds, they are still higher in deep mines. Haldane observed temperatures of 89° to 95° in Cornish tin mines, the wet and dry-bulb temperatures being the same, as the air was absolutely saturated with moisture. Under such conditions the body temperature rapidly rises, and heat stroke may supervene. For instance, in a mine at 94° Haldane found that when he was very lightly clad, and was doing no work, his body temperature rose to 104·2° in less than two hours. As the result of a number of experiments on himself and other subjects, he came to the conclusion that the endurable limit of temperature is about 88° (wet-bulb), if no work is being done, whilst it is 78° if a moderate amount of mechanical work, such as ascending steps at the rate of 13 ft. per minute, is done. At higher wet-bulb temperatures than these the body can no longer control its temperature, and it rises rapidly.

It may naturally be inquired how it is that the tin miners manage to do any work at all. Haldane pointed out that, as a matter of fact, they worked in an extremely leisurely fashion and they stopped in the mines only a short time. Even then their body temperature went up considerably, unless they were able to work in a draught, such as might be caused by the air escaping from the rock drill. He himself found that in an air current at a velocity of about 150 ft. per minute the endurable limits of temperature under the conditions above mentioned were raised from 78° and 88° to 85° and 93°, respectively.

There is another factor of considerable importance, viz., acclimatization. In the course of an investigation in which I repeated and extended some of Haldane's observations, I found that in a few weeks my endurable limit of temperature rose some 6° F. My experiments normally lasted for three hours, and during this time I was step climbing (at the rate of 13½ ft. per minute) for 44 minutes per hour. When moderately clad, my endurable limit of temperature was 78° at first and 85° a month later. When no clothing was worn, it was 83° at first and 88° five weeks later. Hence the endurable limit of temperature of the tin miners was probably about 90°, when doing moderate work, but in any case it is clear that if they were to achieve even a very limited degree of efficiency, it was essential that they should have the cooling power of the body increased by good ventilation.

Direct observations on the work capacity of natives in the deep gold mines of South Africa have recently been made by Orenstein and Ireland.* The work was done on a rotary ergometer with a hand break, and on a hammer dynamometer which registered the number and force of the hammer blows. The instruments were worked for periods of several hours at depths up to 5,260 ft. from the surface. The wet-bulb temperature was sometines 87° and the dry-bulb a degree higher, so that the air was nearly saturated with moisture. It was found that when the dry kata cooling power fell below 6, working efficiency deteriorated, and it was calculated that with cooling powers of 5, 4, 3, 2, and 1, the efficiency fell to respectively 90, 80, 70, 60, and 50 per cent. of the normal. Increased ventilation had a great effect, for when a small fan, with a capacity of about 2,000 cu. ft. of air per minute, was turned on at a distance 15 ft. from the worker, his output increased by as much as 46 per cent. Observations made in various parts of a representative mine section showed that on an average 20 per cent. of the output was lost because of the inadequate cooling power of the air. This was the direct and immediate loss, apart from any indirect loss due to sickness caused by over-fatigue.

These observations on tin and gold mines apply also to deep coal mines, and it is evident that in all of them the efficiency of the miners can only be achieved by paying close attention to the ventilation. Care must be taken that the air currents, though adequate for their purpose, are not too powerful, as it is very easy for the miners, who are bathed in perspiration and wear few if any clothes, to get chilled.

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* Journal of Industrial Hygiene, Vol. IV., pp. 30 and 71, 1922.

The Effect of Atmospheric Conditions on Efficiency in Iron, Steel, and Tinplate Production.

We have seen that in weaving and in deep mines the atmosphere is both hot and humid, but high temperature alone, without any excess of humidity, may diminish efficiency considerably, unless its effects are counteracted by adequate ventilation. Take, for instance, the work of the tinplate millmen, who roll out red-hot bars of steel into thin sheets, which are subsequently tinned. I investigated the output of five factories for periods of 1½ to 7 years, and I found that in all of them there was a distinct seasonal variation, output being at a maximum in the coldest months of the year, and at a minimum in the hottest months, with intermediate values in the intermediate months. The extent of the seasonal change differed considerably in different works. In one of them, where a good ventilation was induced by large revolving paddles immediately above the heads of the men, the summer output (July and August) was only 3 per cent. smaller than the winter output (December and January). In another works, where the system of artificial ventilation was not so good, the summer output was 6·4 per cent. smaller than the winter one, whilst in a third works, where there was no artificial ventilation whatever, it was 13·4 per cent. smaller in the summer. For these and other reasons it was concluded that the installation of a thoroughly efficient system of ventilation in an unventilated works might increase the average output for the whole year by about 12 per cent., as well as add greatly to the comfort of the men.

Seasonal variations of output were likewise observed in the hot and heavy processes of iron and steel manufacture. The output from a hand-charged blast furnace during the summer months (June to September) was 16 per cent. less than during the rest of the year, though a small part of this difference was due to the greater waste of heat in the summer, resultant on the larger quantity of moisture contained in the air blast. The output of an open-hearth steel works, where the shops were narrow and had a low-pitched roof, was 11 per cent. less in summer than in winter, whilst other and better ventilated works showed very little seasonal variation. Again, the output of an old-fashioned rolling mill, where most of the manipulation of the red-hot steel ingots was effected by hand labour, was 10 per cent. less in the summer than in the winter, whilst a modern works, in which the ingots were moved and directed by machinery, showed no seasonal variation whatever. Still again, the output of men engaged in puddling wrought iron, which is effected entirely by hand labour, was found to be 6 per cent. smaller in summer than in winter.

There can be little doubt that similar variations of efficiency occur in many other industries when suitable precautions to avoid or neutralize the effect of high tempratures are neglected, though at present we have no numerical proof of their existence. In laundry work, for instance, high temperatures are very frequently met with. Miss May Smith investigated the atmospheric conditions in the hand-ironing and calender rooms of 22 laundries, and she found that they often showed temperatures well over 90°. The dry kata cooling power of the air frequently fell to below 3, and sometimes below 1. In a few of the rooms the high temperature was largely neutralized by good ventilation, and air currents of over 100 ft. per minute were observed, but this was the exception. In quite a large number of the rooms the air velocity was under 30 ft. per minute, and in a few of them under 20 ft.

The Effect of Atmospheric Conditions on the Frequency of Accidents.

Atmospheric conditions influence efficiency indirectly through the effect they have on the frequency of accidents. Well over 100,000 industrial accidents are notified to the Chief Inspector of Factories every year, whilst the number of minor and unreported accidents is probably at least ten times greater than this, so even a small percentage reduction in accident frequency would have a considerable effect on total incidence. One way of achieving a reduction is by paying more attention to the temperature conditions under which industrial work is carried out, as is proved by some data which Mrs. Osborne and I obtained during the war. We installed thermographs in two large shell factories, and thereby obtained a continuous record of temperature for nearly a year. We tabulated the frequency with which accidents were treated at the dressing stations, and we found that it was greatly influenced by the temperature of the shops. It reached a minimum at 67°, and at temperatures below and above this point it showed a rapid increase. Thus, at 57° the accidents were 16 per cent. more numerous than at 67°, and at 47°, 32 per cent. more numerous. Presumably the hands of the workers tended to get numbed at low temperatures, and the loss of dexterity thereby entailed increased the risk of accident. At 77° the accidents were 23 per cent. more numerous than at 67°, probably because the high temperatures led to carelessness and inattention on the part of the workers, with a consequent increase of accident liability.

The optimum temperature for accident immunity is rather higher than that for working efficiency, as this appears to be about 60° to 65° for work involving moderate muscular activity; but accident frequency is only slightly greater at these temperatures than at 67°, so probably this is the best temperature range to aim at.

The Effect of Atmospheric Conditions on Sickness and Mortality.

There can be no doubt that unhealthy atmospheric conditions have a considerable effect on the health of the workers, and seriously increase their mortality rate as well as their sickness. It is impossible, however, to determine the effect in exact numerical terms, because of the many other factors which play a part. For instance, a comparison of the sickness experienced by a group of

500,000 agricultural workers with a group of 30,000 iron and steel workers showed that the latter experienced from 32 to 49 per cent. more sickness than the former. As already indicated, this was to some extent due to the unfavourable atmospheric conditions under which some processes of the iron and steel industry are carried out, but this was probably not the chief cause. Again, Rusher and I found that in the iron and steel trade the men who worked at the highest temperatures, viz., the steel smelters, experienced the most sickness, and lost 23 per cent. more time from this cause than the average. Puddlers and tinplate millmen came next, and lost, respectively, 20 and 12 per cent. more time than the average; whilst engine men, crane men and general labourers, who worked under normal temperature conditions, showed 9 per cent. less sickness than the average. These differences were due partly to the fatigue of heavy work at high temperatures, but partly also to the fact that the men get overheated, and then catch chills or get rheumatism from sitting about in their damp clothes.

To illustrate the effect of atmospheric conditions on mortality, use may be made of the Decennial Report* on comparative mortality in various occupations issued by the Registrar-General. The accompanying table shows a small sample of the statistics relating to the 1900–02 and 1910–12 periods. The "comparative mortality" figures of men between the ages of 25 and 65 are recorded, and also, in brackets, the mortality of all the male population (occupied and retired) from phthisis and from other respiratory diseases (except influenza). The phthisis and respiratory disease figures for the various occupational groups are, however, calculated *relative* to those for all males, taken in each instance as 100.

Comparative mortality of all males, occupied and retired, aged 25 to 65 years.

Occupation.	Number of Workers in Group (1911). (Aged 15 and upwards).	Comparative Mortality Figure.			Relative Mortality compared with that of all Males.			
		1900–02.	1910–12.	Per Cent. Reduction.	From Phthisis.		From Other Respiratory Diseases.	
					1900 02.	1910–12.	1900–02.	1910–12
All Males (occupied and retired).	11,600,470	1,004	790	21	100 (187)	100 (141)	100 (177)	100 (119)
Farmers, Graziers, &c.	319,560	596	495	17	41	40	43	54
Railway Engine Drivers, Stokers	71,944	610	536	12	35	40	47	53
Cotton Manufacturers	214,213	1,114	811	27	105	85	127	119
Iron & Steel Manufacturers, &c.†	287,659	1,187	837	30	100	92	178	165
Chemical Manufacturers	53,722	1,065	653	39	52	50	179	139
Glass Manufacturers	27,504	1,260	938	26	151	129	151	143
Bookbinders.. ..	13,070	934	791	15	147	151	98	109
Printers	114,453	994	773	22	160	148	74	79
Tailors	151,722	1,027	799	22	133	132	89	92
Shoemakers	193,253	984	820	17	145	157	84	92
Potters, Earthenware Manufacturers	39,209	1,493	1,196	20	152	200	267	266
Cutlers, Scissors Makers	14,512	1,566	1,285	18	285	330	178	177

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* Supplement to the 75th Annual Report of the Registrar-General. Part IV. (*H.M Stationery Office*).

† In this group the data for the two periods are not strictly comparable.

It will be seen that in the healthiest occupations such as farming and engine-driving the comparative mortality was only about three-fifths as great as that of all males, whilst the mortality from phthisis and other respiratory diseases was not half as great. In the other occupations enumerated the mortality from phthisis and from respiratory diseases was always greater than that of farmers and engine drivers, but not by any means to a similar extent. For instance, in the "manufacturers" (to use the Registrar-General's term) of cotton, iron and steel, and of chemicals, the mortality from respiratory diseases was in every case considerably higher than that of all males, whilst the mortality from phthisis was considerably lower. On the other hand, in printers, tailors and shoemakers the mortality from respiratory diseases was low, but that from phthisis was high. Finally, in the potters and cutlers the mortality was very high, both from respiratory diseases and from phthisis. These striking differences are presumably related in some way to the special character of the occupations, and in order that we may aim at remedial measures, it is important that we should identify the chief causes of the variations.

The first group of occupations mentioned have one factor in common, for they are all liable to be carried on under conditions of high temperature. Many of the processes in the cotton industry require a hot and humid atmosphere, and it has already been pointed out that those of the iron and steel industry, such as the smelting and rolling of steel, are often pursued at extremely high temperatures. The temperature conditions are not usually so adverse in the chemical industry, but in the glass industry, where there is a high mortality from respiratory diseases, the temperature conditions may be very trying. The high temperatures in these industries are for the most part intermittent. In consequence, the workers are liable to get overheated, and then, by exposing themselves, to contract chills.

In the second group of occupations mentioned, where there was a high mortality from phthisis but a low one from other respiratory diseases, the workers do not carry on their labours at high temperatures, but they are often crowded together in ill-ventilated shops. This proximity is liable to promote phthisis, especially if the natural lighting is bad. It is true that the observations of Hambly and Bedford* show that in large boot and shoe factories the atmospheric conditions are reasonably good, but the recent observations by Edge† in the printing trade are not nearly so satisfactory. Several printing works in London were investigated, and in summer time the kata cooling power was sometimes less than 3, and occasionally under 2. In winter time the conditions were better, but the velocity of the air currents was very seldom over 30 ft. per minute and was often under 20 ft. This poor ventilation, coupled with the fact that in many printing works there is not much sunlight and a good deal of artificial light, may be responsible for the mortality figures recorded. In the tailoring trade some observations are recorded by the Chief Inspector of Factories, in his Annual Report for 1921.* The data quoted relate to 38 tailoring and dressmaking workrooms, mostly basement rooms, and in 6 of them the kata cooling rate was under 6, in 31 it was between 6 and 8, and in 1 it was over 8. So far as these observations go, therefore, the ventilation seems reasonably good, but it is desirable that further investigations should be made.

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* Preliminary Notes on Atmospheric Conditions in Boot and Shoe Factories (*Ind. Fat. Res. Bd., Report No.* 11).

† The Kata-thermometer, etc. (*Med. Res. Counc., Special Report Series No.* 73.)

In the third group of occupations mentioned, viz., the manufacture of pottery and cutlery, the comparative mortality figure is in each case about 50 per cent. above the average. This high mortality is due chiefly to phthisis and other respiratory diseases, which were responsible for two or three times the average number of deaths. Moreover, the relative mortality from these causes showed no improvement in the decennium, though it is probable that the new regulations in the pottery trade, which came into force in 1911, will show a very favourable effect when the 1920–22 figures are available. Sooner or later a great improvement should appear in the mortality figures of cutlers and scissor makers, for machine grinding is on the increase, and from some of these machines practically no dust is given off.

For a complete investigation of the points referred to, it would be necessary to take account of the whole of the Registrar-General's figures. Further, most of the occupational groups recorded by him contain large numbers of persons not exposed to risk, so that with a more detailed classification the effects suggested above might prove to be much more marked.

Conclusion.

This brief account of the influence of atmospheric conditions on industrial efficiency is necessarily very fragmentary, as our knowledge of the subject is so imperfect. Nevertheless, sufficient information has been adduced to prove that the atmospheric conditions under which many of our industries are carried on frequently have a very marked effect on the health and efficiency of the workers. It follows, therefore, that it is our duty to extend the observations to every industry in which it is thought that the atmospheric conditions are defective, and to obtain exact information. If we know the extent of the disease, we shall be in a much stronger position when we insist on the importance of adequate remedies, than if we can speak only of probabilities.

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* Cmd. 1705., p. 100.

E.—FUTURE INVESTIGATIONS IN THE POTTERY INDUSTRY.

By H. M. Vernon, M.D.

It is realized that Report No. 18 of the Industrial Fatigue Research Board on "Two Investigations in Potters' Shops," represents only a small beginning of the investigations which, it is hoped, will be made in the pottery industry at some future date. Though the Board is not contemplating the initiation of such investigations in the immediate future, it seems worth while to point out some of the directions in which they might be made, when opportunity offers.

The Drying of Ware.

The first investigation to suggest itself is a continuation of the admittedly incomplete observations described in the Report on the effects of temperature, relative humidity, and air currents on the drying of ware of different sizes. The drying of small ware could be best investigated in a technological laboratory devoted to the study of pottery problems, and for this purpose it would be necessary to have a small experimental drying chamber in which the temperature and air currents could be accurately controlled and measured. It would probably be found that the temperature could be most easily controlled by using an electric heater as the source of heat, whilst the velocity of the air currents could be varied by opening and shutting air holes at the bottom of the chamber, and lengthening or shortening the air shaft fixed at the top. Both wet bulb and dry bulb observations of temperature would be necessary, whilst the air velocity could be ascertained by kata thermometer and anemometer. The rate of drying of the ware, such as plates, cups and saucers, could be determined by systematic weighings. Such investigations, being of a technical nature, would be more appropriately carried out by pottery experts than by investigators to the Board, but there are other problems which are well suited to the activities of the Board. Among them is the investigation of pottery dust, and the application of Time and Motion Study to the production of pottery.

Pottery Dust.

As was pointed out in Report No. 18, the comparative mortality of male potters from phthisis and other respiratory diseases in 1900-02 was two to three times greater than that of other males living in the district, and this was undoubtedly due in large part to the inhalation of pottery dust. Thanks chiefly to the regulations suggested in the Report of the Departmental Committee on Lead, etc., in Potteries, which was issued in 1910, the evils of dust inhalation have been greatly reduced, and in many directions almost overcome ; but there is still room for improvement.

In tile manufacture, for instance, it appears that both tile pressers and fettlers often work in a distinctly dusty atmosphere, but only actual quantitative estimations can show if the dust is so great as to be likely to exert an injurious action on the workers. It is very desirable that such estimations should be made, for the observations carried out by G. E. Duckering, and published in the above-mentioned Report (1910), are scarcely sufficient. Though of great value, they were made by a method which more recent investigations have shown to be, in some cases, inadequate. Duckering used a cotton filter, and this retains the large particles of dust which are not likely to reach the lungs, and gives no reliable figures as to their size distribution. The Owen or the Palmer apparatus, on the other hand, enables counts to be made of the total number of particles in a given volume of air, and the relative proportion of large and small particles. It is the small particles which are specially harmful, and it has been suggested that instead of basing our standard on the weight of particles, we should adopt the number of particles 1 to 10 microns in diameter (cf. " Journal of Industrial Hygiene," Vol. II., 378, 1921).

Time and Motion Study.

My observations on Time and Motion Study were few in number and were purely of a preliminary character, but they were sufficient to indicate that an extended study would yield results of value. A study of the output figures of groups of plate makers, saucer makers, and towers (i.e., women engaged in removing the rough edge of plates, saucers, etc.) over a two-year period, showed that the quickest workers consistently attained an output about 50 per cent. greater than that of the slowest workers. All the workers were on piece rates and had been at their job for sufficient time to attain a steady rate of production, and yet they showed these marked differences of productivity. The differences were due partly to the fact that some of the workers kept to their work more steadily and persistently than others, but I think that they were largely if not chiefly due to differences in the character of the movements made in carrying out the industrial operation. For instance, I noticed that the quickest towers and fettlers always put down their metal strip and sand-paper in the same place, whilst the slower ones put them down anywhere, and in particular threw down light materials, such as tow or sand-paper, so that they were carried away to various places by the exhaust draught in which the towing process is carried out. Again, in the final dusting the quick towers only dusted the plate for just over one complete revolution, whilst the slow ones allowed it to revolve several times against the tow.

An extended study of the towers, and of the other groups of workers, would no doubt have revealed other unnecessary movements made by the slower workers, and perhaps even by the quick ones. In another class of operation the difference between the rate at which the quick and the slow workers proceeded was more striking than in the operations mentioned. This was in the packing of the glazed biscuit ware in saggers by the placers. The few observations made showed that the quickest workers packed quite twice as fast as the slowest ones. I did not endeavour to ascertain the reasons of these differences, but no doubt they could be tracked down by extended time and motion study. It seems to me that in these and other industrial processes much could be done by the workers themselves, without any outside assistance. If a foreman pointed out to workers A, B, and C that their rate of production, as shown by their wage payments, was consistently a good deal lower than that of the quickest workers, such as D, E, and F, and advised them to take a few minutes off from their work occasionally in order to watch these quick workers, they would generally be able to learn some of the secrets of a big output, unless they were exceptionally stupid. It is improbable, however, that they would achieve so high a standard as they could with expert advice and assistance.

Other Labour-saving Devices.

In addition to the time and motion study methods suggested, much can be done by the introduction of direct labour-saving appliances. To anyone acquainted with the mechanical transport and other labour-saving machinery habitually used in most large industries, the backward state of the pottery industry comes as a shock, for it is quite the exception for a pottery works to possess any kind of mechanical carriers. A potter engaged in plate-making may need a ton of clay a day, yet it is all brought to him by a helper, who carries a 40 lb. lump on his shoulder, and therefore needs to make more than fifty separate journeys a day. A boy helper carries every mould from drying stove to potter, and vice versa. The potter himself carries all his clay ware to the shed adjoining the ovens. Each oven holds about 3,000 saggars, which are piled in bungs 20 ft. high, and each saggar, weighing about 70 lb., is carried by a placer, who usually has to mount a tall ladder, balancing it on his head. The emptying of the ovens is effected by similar methods, though it sometimes has to be carried out at a temperature of over 120° F. Again, all the transport of the ware from one shop or warehouse to another is effected by human labour. A man may carry on his shoulder a basket or board of it, whilst the boys and girls usually have not got even this appliance. It is true that, according to the regulations, they may not carry more than 30 lb. weight until they are 16 years old, but they often break the rule.

Why are the potteries so backward in utilising mechanical transport? Firstly, boy and girl labour used to be extremely cheap, although since the war it is so no longer. Then, most pottery works are comparatively small concerns, employing less than 200 workers, so the owners do not care to incur the necessary outlay. Again, pottery is very fragile at certain stages of its manufacture, and special precautions would have to be taken in its carriage. In spite of these objections, there can be no doubt that, sooner or later, pottery works will have to instal mechanical transport. Some of them are already doing it slowly by small instalments, but many works are so old-fashioned that it is difficult to effect much improvement without complete reorganization and re-building.

The pottery works of the future will probably be considerably larger than at present. The old-fashioned conical ovens will be completely replaced by tunnel ovens or chamber kilns, heated by producer gas, for tunnel ovens burn only a third or a fourth as much fuel as the conical ovens, and they save half the labour of the placers. Those at present erected are not so efficient as they might be, as all the heat radiating from their walls is wasted, whereas it might be utilised for drying the ware, if suitable chambers were erected on the top and sides of the tunnel. If this were done the transport of the moulds and ware between potters and drying chambers would have to be effected by belt conveyors or other forms of mechanical transport, and similar methods of carriage could be used to convey the ware to the placers, who were loading it on to the wagons. However, the ideal lay-out of an up-to-date pottery works is a question for experts, among whom the expert in mechanical transport would hold a most important place. An adequate scheme would relieve the potters of much of their heavy work, and should afford them healthier workshop conditions than those usually met with at the present day. The placers, in particular, would no longer have to carry their loads such distances, or to work at the high temperatures to which they are now sometimes subjected.

A very striking account of the application of modern conveying methods to a pottery works has just been published.* The firm, an American one, were engaged in manufacturing electrical porcelain, and they introduced a complete transport system at every stage of the manufacture. The moist clay from the filter presses was taken to and from the drier, crusher and dust mill by means of jack trucks, belt conveyors and gravity roller conveyors, but most ingenious of all was the system adopted for loading and unloading the kilns. The same conveyor was used for both processes, the top run being used for loading, and the bottom one for unloading. It consisted of a canvas belt moving at the rate of 25 to 30 feet per minute. It was situated 8 feet away from the doors of six kilns, and opposite each door was placed a portable belt conveyor connecting the main belt with the kiln. It delivered the saggars at the rate of 400 per hour right into the kiln, where they were dealt with by the placers. For unloading the kilns a portable gravity conveyor was used, extending from inside the kiln to the lower strand of the main belt conveyor. The efficiency of the system may be judged by the fact that whereas it formerly took ten men 20 hours to load a kiln, it now takes five men 8 hours. In unloading, it now takes six men 8 hours, instead of five men 20 hours, and in addition the breakages are very much reduced. The saving in cost is said to amount to £25 a day, or sixty times the interest charges on the outlay incurred in installing the whole conveyor system.

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* cf. "Industrial Management," Dec. 14, 1922.

F.—A NOTE ON MACHINE DESIGN IN RELATION TO THE OPERATIVE.

By H. C. Weston, M.J.Inst.E.

The introduction and development of power-driven machines has effected an enormous saving of time and energy, not only by increasing the rapidity of production through the substitution of mechanical power for human effort, but also by changing the character of the manipulations which remain to be performed by the operative. So great has this economy been, that it has brought with it a tendency to overlook the possibility that, while industrial machinery may be admirably adapted to the performance of its mechanical functions, it may be incompletely adapted to the needs of the human organism, upon whose efficient co-operation it depends for its productive value. The attention of the machine designer is, properly enough, directed primarily to the perfection of his machine from the point of view of its mechanical and functional efficiency; and this machine, even though it be designed, not with deliberate disregard, but with a lack of appreciation of the convenience of the operative, is still a more economical agent for production than is the manual worker engaged upon the same task. This fact has no doubt helped to obscure the importance of making the fullest provision for the needs of the operative in the design and construction of machines.

Again, the manufacturers of many of our industrial machines are not themselves users of their own products, and in such a circumstance the importance of details which are of great concern to the operative can be easily under-estimated. The effort required to operate a certain control, for instance, may appear in no way excessive when it is operated once, or for a short time during a test, but under normal working conditions, when it has to be operated perhaps fifty or sixty times an hour, the energy expended by the operative becomes very considerable. Similarly, the adoption of a certain posture necessitated by the construction of a machine may be a matter of small consequence when it is adopted for a short time, but when it has to be maintained for a large part of the working day it may become not only unpleasantly fatiguing but definitely injurious to health.

Often, no doubt, mechanical and technical requirements make it very difficult to secure adequate provision in the design of a machine for the comfort and convenience of the operative, but in other cases the needs of the operative have been sacrificed or subordinated in the effort to obtain such commercial advantages as low prime cost and small power consumption. A great many of the machines now employed in industry have reached a very high stage of development as regards their mechanical and functional efficiency, owing to the number of improvements made on their earlier designs as the result of experience in their operation and of the development of better tools, materials and methods for their manufacture. In the course of this development no doubt a number of those features of design which experience showed to be detrimental to the operative, have been modified to some extent, but it has sometimes happened that an alteration made to one part of a machine has not been accompanied by an appropriate alteration of some other part to which it is related, and with which the operative is directly concerned. In such circumstances an improvement in one direction may serve to aggravate a point of design which was already detrimental to the operative, or to create some new defect. An instance of this kind exists in a certain type of laundry machine, in which the lightening of a roller attached to a lever carrying a pedal and a balance weight has not been accompanied by a corresponding lightening of the balance weight, with the result that the pedal—previously requiring an unnecessary expenditure of energy for its operation—is now still more difficult to operate.

In some cases the defects existing in machines are of a simple and easily remedied form, and yet are such as could not have been wholly anticipated by the designers, even if special consideration had been given to the needs of the operative, so far as these were known, when the machine was designed. Such defects may remain unsuspected for a very long time and may eventually be disclosed only when some disability or other pathological condition having a high incidence among the operatives, can be shown to be due to their influence. A case in point was investigated some years ago by Collis and Eatock,* who found that the prevalence of Dupuytren's contraction among lace machine minders was directly related to the frequency with which the levers and wheels of the machines were manipulated, the power required to actuate them, and their size, shape and position. Here, the disability to which the operatives were subject was of a permanent nature and resulted from frequent exposure of the palm of the hand to excessive pressure during a long period. So far as shape was concerned, the levers were of common types such as are employed in a large variety of machines, but their positions and the inadequacy of the leverage provided, having regard to the resistance to be overcome, combined in producing the effect observed. That the necessity for studying the needs of the operative was unrealised by the makers of these machines is shown by the fact that they did not know what power was required to actuate the levers and wheels and that a test made on two machines of the same size, built at the same time by the same firm, showed a variation of 50 pounds in the force required to operate the same control.

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* Report of an Inquiry on Dupuytren's contraction as a Disease of Occupation, with special reference to its occurence among Minders of Lace Machines. (Home Office, 1912.) (*H.M. Stationery Office.*)

This question of power required in operating machine controls is one which, generally speaking, appears to have received insufficient consideration at the hands of designers, and in a large number of machines of different types the effort which has to be exerted is unnecessarily great.

In respect of accident prevention, recent years have witnessed considerable improvement in the design of machines, as the result, both of the operation of the Factory Acts and of a growing appreciation of the loss to industry represented by accidents to workers, and the accessory devices used in guarding dangerous parts of existing machines, are, in some cases, now being incorporated in the original design of new machines. The case of disabilities incurred by long continued operation of particular machines is, however, in a different category, and although such cases are relatively few, probably all of them could be avoided in the future, if certain rules, based on physiological principles, could be laid down for the guidance of machine designers.

Far more widespread than either accidents or disabilities is, however, the waste of time and energy of the operatives of machines which are so designed that utilization of the most economical body movements, the most effective groups of muscles, and the habits of action most easily acquired and maintained, is difficult or even impossible. There is some evidence that this aspect of machine design is beginning to receive some measure of the attention it deserves, particularly from designers whose machines have now reached such a high standard of mechanical and functional perfection, that the scope of improvement in this latter direction has been brought within very narrow limits.

On the other hand, the users of machines are in some cases altering existing types where it is obvious to them that increased convenience in operation by the worker will result. This practice is open to the objection that unless great care is taken, alteration of one part of an existing machine, while effecting an improvement in one respect, may affect some other part of the machine in such a manner as to introduce a new defect. It is, therefore, most important that correct design should be secured in the first instance. It is difficult to see how this can be obtained to the fullest extent except as the result of definite research, undertaken with the object of determining such physiological and psychological facts as should be borne in mind when designing machines, the forms of mechanism and mechanical combinations which will conform to the needs of the operative, and the extent to which the ideal conditions thus established can be secured in practice without interference with the function of machines or undue increase in their prime and running costs.

Although in recent years much work has been done with the object of discovering means for reducing the fatigue and increasing the efficiency of industrial workers, the question as to what extent unnecessary fatigue and inefficiency is produced by conditions imposed upon the worker by the constructional features of his machine has been neglected. This is not surprising, since the machine is usually regarded as unalterable—as, indeed, many existing machines are, except within very narrow limits—and the attention of investigators has therefore been directed mainly to securing some immediate benefit to the workers by improving those conditions which are more readily changed, such, for instance as the disposition of raw materials and tools and environmental conditions such as ventilation and lighting.

Time and motion study, when it has been applied to mechano-manual operations, has enabled a better, or perhaps the best, method of work *with the existing machine* to be found, but the method which is really ideal for the worker is often unattainable without some alteration in the design and construction of the machine with which he has to co-operate. In the case of purely manual operations, account has been taken of the form and size of the tools and materials with which the worker has to deal, as well as of his method of manipulating them, and much of the economy of movement and effort which has resulted from the application of time and motion study to such operations has been effected only after some alteration has been made to one or both of these elements. In work involving co-operation with a machine, the design and construction of the machine itself may exert an influence upon the methods of work adopted by the operative similar to that exercised by the form and size of tools and materials in manual operations, and it is therefore just as necessary to consider the possibility of altering the machine in order to enable the operative to adopt a better method of work.

Some of the points to which special attention should be paid in designing machines have already been mentioned. These include the shape, size and position of levers and hand-wheels, and the power required to operate them. Others which are obviously important are the height of the working plane, the area which has to be kept under observation, the extent to which the operative may be required to reach, both in horizontal and vertical direction, and the number of controls, together with the order in which they are arranged.

As the result of special investigations, it should eventually be possible to provide the machine designer with data which will enable such points as these to be dealt with in a manner much more conducive to the welfare and efficiency of the machine operator than is possible at present. Any general rules of design which it may be possible to lay down in the future must, however, necessarily refer only to those elements which are common to most machines, and special cases will arise in which it is desirable that the designer should have at his disposal some means by which he can ascertain whether he has incorporated in his design features which are likely to prove detrimental to the worker or to involve undue difficulty in operation. In this way a great deal of the fatigue and inefficiency now existing as the result of lack of adaptation of the machine to the man could undoubtedly be eliminated in the future—just as vocational guidance affords a means for avoiding much of the inefficiency arising from the choice of an occupation for which one has little or no natural aptitude. Whilst, however, a mistaken vocation can often be changed, even though it be after the waste of more or less valuable time, the duration of the ill-effects of an unsuitably designed machine is frequently limited only by the life of the machine, during which probably several operatives are subjected to its influence.

SUPPLEMENT.

LIST OF REPORTS AND OTHER PUBLICATIONS.

I.—REPORTS OF THE BOARD.*

A.—General and Miscellaneous Series.

First Annual Report of the Industrial Fatigue Research Board to March 31st, 1920. (31 pages). [Price 6d. net, post free 7½d.]

[An account of the origin of the Board, the methods of research employed, and the investigations undertaken.]

Second Annual Report of the Industrial Fatigue Research Board to September 30th, 1921 (with Analysis of Published Work). (65 pages). [Price 1s. 6d. net, post free 1s. 7½d.]

[Part I contains a review of the work carried out during the 18 months ended 30th September, 1921. Part II consists of an analysis of the published work of the Board arranged on a systematic plan, with full references to the separate reports.]

No. 4.—The Incidence of Industrial Accidents upon Individuals with special reference to Multiple Accidents, by MAJOR GREENWOOD, M.R.C.P., and HILDA M. WOODS. (28 pages). [Price 6d. net, post free 7½d.]

[A contribution to the study of the causation of accidents, based on a statistical investigation of certain accident records kept by the Ministry of Munitions. The results indicate that accidents are very largely due to a special susceptibility inherent in the personality of the individual, so that the bulk of accidents occur amongst a limited group of individuals, and that the incurring of one accident is in itself of minor importance in connection with the probability of incurring a second or subsequent accident.]

No. 6.—The Speed of Adaptation to altered Hours of Work, by H. M. VERNON, M.D. (33 pages). [Price 1s. net, post free 1s. 1½d.]

[The report compares, by means of data derived from previous investigations and of others hitherto unpublished, the speed with which workers in different occupations adapt themselves to altered hours of work, and shows that whereas any increase in hourly output resulting from reduction of hours is gradual, in the converse case of a decrease in hourly output due to lengthening of hours the effect is immediate. A further important point, emphasising the interdependence of occupations in a factory system and indicating that reduction in hours may be fruitless unless an operation is considered in all its bearings, is brought out by the fact that in certain engineering processes the hourly output of women operatives working on short hours with the men tool-setters and labourers working on long hours was less than when the men's hours were diminished and the women's increased.]

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*The Reports issued by the Board can be purchased through any Bookseller or directly from H.M. Stationery Office at the following addresses :—Imperial House, Kingsway, London, W.C.2, and 28, Abingdon Street, London, S.W.1 ; 37, Peter Street, Manchester ; 1, St. Andrew's Crescent, Cardiff ; and 23, Forth Street, Edinburgh.

The offices of the Board are unable to supply them directly.

Applications by post to the above addresses should quote the description in full of the publications wanted, and should be accompanied by the price as indicated in the list.

No. 12.—Vocational Guidance (a Review of the Literature), by B. Muscio, M A., Investigator to the Board. (57 pages). [Price 1s. net, post free 1s. 1½d.]

[A critical survey of the literature on the subject with complete bibliography.]

No. 13.—A Statistical Study of Labour Turnover in Munition and other Factories, by G. M. Broughton, M.A., Ethel M. Newbold, B.A., and Edith C. Allen. (88 pages). [Price 3s. net, post free 3s. 2d.]

[The report deals with the labour turnover (*i.e.*, the rate of change in the working staff) between the years 1916 and 1920 in ten munition and three other factories, and is based largely on the employment records already available at the Ministry of Munitions. It points out the advantages of periodical revision by employers of the state of labour turnover in their factories. The necessity of adopting some method of estimating labour turnover is urged, since a slight wastage may remain entirely undetected, and if unchecked will involve a serious waste of time on the part of both employers and employee. Labour turnover may also be used to indicate to some extent internal conditions in the different departments of a factory. A test is explained, which indicates whether wastage is unduly high and calls for further investigation as to the cause, and notes on factory records and record keeping are included.]

No. 14.—Time and Motion Study, by E. Farmer, M.A. (63 pages with plates), [Price 2s. net, post free 2s. 1½d.]

[Part I consists of a critical review of the past work on the subject, including Taylor's and Gilbreth's methods. Part II is an account of a series of experiments carried out by the author in a confectionery factory, in which motion study was applied, not to determine the movements which took the shortest time to perform, but to discover those movements which when properly learned the worker would find easiest to perform. The results obtained in two manual processes showed increases in output of 27 and 88 per cent. respectively. The report includes photographs showing the needlessly large number of movements used by untrained workers, and the improvement following a short course of training. A full bibliography, including references to periodicals, is appended.]

No. 16.—Three Studies in Vocational Selection, by B. Muscio, M.A., and E. Farmer, M.A. (86 pages). [Price 1s. 6d. net, post free 1s. 7½d.]

[Part A (The Psycho-Physiological Capacities of Hand Compositors) describes an investigation on vocational selection conducted amongst hand compositors in printing works. After close observation of the work and of the particular capacities demanded, tests which seemed to be prima facie suitable were selected and applied to two groups of about 25 compositors. The subjects were then graded first according to the marks obtained in the tests, and secondly, according to the actual working proficiency shown by each, and the two gradings compared. Such tests as were shown to be unnecessary were then eliminated and a grading based on the remaining tests correlated with the proficiency grading. In this way, the high correlation co-efficients of ·80 and ·71 were obtained for the two groups.

Part B (The Measurement of Strength with reference to Vocational Selection) is concerned with the physical side of vocational selection, and is based on observations of the range of muscular strength amongst about 2,300 youths in Manchester and industrial Essex. The results show first that a combination of grip and weight gives a useful indication of general muscular strength, and secondly, that there is a consistent difference between youths of the same age in the two localities.

Part C (Physical Measurements in a Confectionery Factory) is an account of a somewhat similar investigation, based on the finger and hand measurements of girls in a confectionery factory. The results show that two distinct types exist, designated long-spanned and short-spanned, and that each of these types is specially prevalent in certain occupations, suggesting that the former type is desirable for some kinds of work and the latter for others. A more intensive treatment of the data led to rather indefinite results, probably because other and more powerful factors in proficiency tend to mark the influence of physical type.]

No. 19.—Two Contributions to the Study of Accident Causation, by ETHEL E. OSBORNE, M.Sc., H. M. VERNON, M.D., and B. MUSCIO, M.A. (xi. and 36 pages). [Price 1s. 6d. net, post free 1s. 7½d.]

[Part A (The Influence of Temperature and other conditions on the Frequency of Industrial Accidents) is based on observations carried out during the war in certain munition factories in which accurate records of accidents of all kinds were kept. The results indicate that there is a minimum frequency of accidents at a temperature of about 67·5° F., and that both above and below that temperature accidents tend to increase in number. The ultimate subjective causes of accidents are also discussed, and from a comparison of the day and night incidence the conclusion is reached that speed of work, the psychical state of worker, and, in some instances, fatigue all play a part.

Part B (On the Relation of Fatigue and Accuracy to the Speed and Duration of Work) is an account of a laboratory research undertaken in order to determine to what extent accuracy of movement is affected by (*a*) speed of work, and (*b*) fatigue as measured by the duration of work. The results, which are admittedly only tentative, indicate that the former is the important factor, since accuracy diminishes as the speed is increased, but actually increases over a continuous spell of work at a constant speed.

The preface to the report contains a short analysis of the work carried out on the personal side of accident causation.]

B.—Metal Series.

No. 1.—The Influence of Hours of Work and of Ventilation on Output in Tinplate Manufacture, by H. M. VERNON, M.D. (31 pages, with plates). [Price 6d. net, post free 7½d.]

[Compares the fatigue and output of mill-men working on shifts of four, six and eight hours, and in factories with different systems of ventilation, the data being obtained partly from existing records and partly by direct observation. The results show that for this particular work when an eight-hour shift was reduced to a four-hour shift the hourly output eventually increased by 11·5 per cent. Similarly on a six-hour shift the hourly output increased by about 10 per cent. compared with that on an eight-hour shift, corresponding to a rise of 8·3 per cent. in total weekly output. The existence of a seasonal variation in output is shown, and attention is drawn to the marked effect of good ventilation on fatigue and output, efficient ventilation probably increasing the average output of an unventilated factory by 12 per cent. or more. Suggestions are also made as to suitable clothing for the work.]

No. 2.—The Output of Women Workers in relation to Hours of Work in Shell-making, by ETHEL E. OSBORNE, M.Sc. (23 pages). [Price 6d. net, post free 7½d.]

[Embodies the result of a small investigation based on the booking of hourly output of 43 women engaged in shell-turning during one week on two twelve-hour shifts and during one week on three eight-hour shifts, and compares the fatigue and output under the two systems.]

No. 3.—A Study of Improved Methods in an Iron Foundry, by C. S. Myers, C.B.E., M.D., F.R.S. (8 pages). [Price 2d. net, post free 3d.]

[A short description of the methods adopted in an iron foundry with the full concurrence of the workers, the introduction of which greatly increased the output for jobs that included machine work.]

No. 5.—Fatigue and Efficiency in the Iron and Steel Industry, by H. M. Vernon, M.D. (99 pages, with plates). [Price 3s. net, post free 3s. 2d.]

[This report is based on investigations of numerous iron and steel works situated in England, Scotland and Wales, where all the workers are now on eight-hour shifts, though in certain districts they were on twelve-hour shifts until recently. It shows that as a result of the reduction of hours, the output from the open hearth steel furnaces went up 2 to 9 per cent., but that there was no change in the output from the rolling mills or the blast furnaces. The timekeeping of the blast-furnace men, however, improved, and it was found possible to reduce the number of men required to run the furnaces.

The effects of fatigue were specially seen in the blast-furnaces men on Sundays, when they worked a sixteen-hour shift, their rate of charging the furnaces (by hand) being 5 to 10 per cent. less than on weekdays, when they worked eight-hour shifts. Again, the rate of charging was 16 per cent. less in the summer than in the winter, and seasonal variations in the output of the heavy workers were likewise observed at the steel furnaces, the puddling furnaces and the rolling mills. Practical suggestions are made for reducing the heaviest work of all, namely, that of the steel melters when fettling (*i.e.*, mending), their furnaces. An attempt is also made to classify occupations according to the fatigue of the work.

Sickness and mortality data relating to 24,000 iron and steel workers were tabulated for a six-year period. Men on the heaviest work experienced the most sickness, the steel melters showing 23 per cent. more than the average, the puddlers 20 per cent. more, the tinplate millmen 12 per cent. more, and the rolling mill-men 8 per cent. more. The excess of sickness shown by the puddlers was due entirely to rheumatism and respiratory diseases. The steel melters showed 26 per cent. greater mortality than the average, and the blast-furnace men a higher mortality still.]

No. 15.—Motion Study in Metal Polishing, by E. Farmer, M.A. (65 pages, with plates). [Price 2s. net, post free 2s. 1½d.]

[The Report describes the effect of applying time and motion study to various processes in a factory where the buffing of spoons and forks is carried on, but the results are applicable with slight modification to all processes of grinding or polishing by means of a revolving wheel. At the beginning of the investigation there were enormous differences in the movements and methods of the workers, and corresponding differences in the amount of wasted energy expended. An attempt was therefore made to systematise the effort required for each process, based in some degree on the methods adopted by the most efficient worker present. The slower and less efficient workers were then trained to adopt the standard method. As the result, the time required to perform a standard task was reduced by 8 to 61 per cent. in one process, and by an average of 30 per cent. in another.

Data are given to show that a beginner, given adequate training, can become an expert worker in a few days, but that left to herself without proper instruction she probably will never become highly skilled and will continue all her life to waste her energies in unnecessary and unproductive movements.

The Report also contains information on the effect on output of rest-pauses and of the provision of seats for the workers.

Finally, a method of measuring the duration, number, and pressure of the strokes used by the workers is described, and the importance of these factors on ease of working is discussed.]

C.—Textile Series.

No. 7.—Individual Differences in Output in the Cotton Industry, by S. Wyatt, M.Sc. (13 pages). [Price 6d. net, post free 7d.]

[Embodies the results of a small preliminary inquiry based on individual differences in output in various processes in the cotton industry as measured by the variations in piece rate earnings, and illustrates the extent to which in each process production depends on human, as opposed to mechanical, efficiency.]

No. 8.—Some Observations on Bobbin Winding, by S. Wyatt, M.Sc., and H. C. Weston, M.J.Inst.E. (40 pages). [Price 1s. 6d. net, post free 1s. 7½d.]

[A full description of the conditions prevailing in the winding department of a certain mill with rather special features. The various factors directly affecting efficiency in winding are discussed at length, and the operations involved in bobbin-winding are analysed into their elementary movements. Finally the relation of machine design to fatigue is illustrated.]

No. 9.—A Study of Output in Silk Weaving during the Winter Months, by P. M. Elton, M.Sc. (69 pages). [Price 2s. 6d. net, post free 2s. 8d.]

[The report deals with the hourly, daily and weekly variations in production in two silk weaving mills, making plain and fancy goods respectively, by analysis of output data collected continuously for four months from 98 looms. The various factors affecting production are discussed, and it is shown that the curve of distribution of output throughout the day has a characteristic shape. A gradual increase in output occurs from December to March, coinciding roughly with the lessened use of artificial light, under which production appears to fall about 10 per cent. as compared with daylight. Suggestions are also made for increasing efficiency, in particular the keeping of certain records.]

No. 17.—An Analysis of the Individual Differences in the Output of Silk Weavers, by P. M. Elton, M.Sc. (38 pages). [Price 1s. 6d. net, post free 1s. 7½d.]

[The report embodies the results of an investigation into output in silk-weaving, but these are applicable with little modification to any type of weaving.

Part I deals with the extent of the differences in individual performance, and shows that while the performance of any given weaver remains at about the same level for any given quality of cloth, there is not definite line of demarcation between good and bad weavers, the two classes merging into one another insensibly. Further, the large, but consistent differences in loom efficiency manifested as between one weaver and another indicate how greatly production in power loom silk weaving is dependent on the human factor.

Part II is concerned with the causes of the differences in individual performance. These have been investigated by means of time study, applied to ascertain how far and in what respect individual differences in method are related to efficiency in weaving. By means of a full classification of the various causes of loom stoppage and observation of the methods adopted in each case, some of these methods are known to be definitely good and others to be definitely bad, indicating the importance of adequate preliminary training in weaving.

Actual specimens of the time analysis sheets containing the data for selected weavers are given and explained, and suggestions are made for its further use.

The report itself is confined to silk-weaving, but the methods described and conclusions drawn are applicable with little modification to power loom weaving in any of the textile trades.]

No. 20.—A Study of Efficiency in Fine Linen Weaving, by H. C. WESTON, M.J.Inst.E. (iii and 28 pages). [Price 1s. 6d. net, post free 1s. 7½d.]

[The report embodies the results of a special investigation conducted into a process, which for successful manufacture a high atmospheric temperature and a high degree of humidity are required. The results indicate that up to a certain limit of wet-bulb temperature (73° F.) productive efficiency increases with the temperature, but that above that limit efficiency falls, notwithstanding the favourable physical effects of the atmospheric conditions, owing to the discomfort and fatigue of the weavers. The physiological view that working disability begins at a wet-bulb temperature of 70° to 75° thus receives confirmation.

The relation of illumination to efficiency is also discussed, and evidence is given showing that the use of artificial light reduces efficiency by about 11 per cent. of its normal daylight value.]

No. 21.—Atmospheric Conditions in Cotton Weaving, by S. WYATT, M.Sc. (x and 36 pages). [Price 2s. net, post free 2s. 2d.]

[The report is based on an extensive series of observations of the temperature and movement of the air, and of its cooling power as measured by the dry and wet kata-thermometer in eight humid weaving sheds. A comparison is drawn between winter and summer observations, and examples are given of the daily variations in temperature and cooling-power with explanations of the differences which occur.

Suggestions are made for increasing the cooling-power by increasing the air movement, and an account is given of a small-scale experiment carried out with this object.

Finally, the atmospheric conditions in humid weaving sheds are compared with those in other factories, and detailed instructions are given for using the kata-thermometer, the instrument with which the observations of cooling-power were made.

The preface contains a short account of the legislative and official action taken in regard to humidified factories in the United Kingdom.]

No. 23.—Variations in Efficiency in Cotton Weaving, by S. WYATT, M.Sc. (vii and 60 pages). [Price 3s. 0d. net, post free 3s. 2d.]

[This report is based principally on hourly output (pick-recorder) readings taken on about 600 looms over a period of one year, amounting in all to over one million. In these the high and uniform standard efficiency generally maintained in cotton weaving is clearly indicated. The variations in efficiency over the year, week and day are fully discussed, and the various factors in efficiency (distinguished as environmental, personal, and physical), analysed. Owing to the large volume of data involved, individual and chance variations are eliminated in the final results, but the general tendencies that emerge may be accepted as real. It is shown, for instance, that at temperatures over 75° F. productive efficiency tends to fall owing to fatigue on the part of the workers, and also that during periods of artificial lighting output may be reduced by 5 per cent.]

D.—Boot and Shoe Series

No. 10.—Preliminary Notes on the Boot and Shoe Industry, by J. LOVEDAY, B.A., and S. H. MUNRO. (32 pages). [Price 1s. 6d. net, post free 1s. 7½d.]

[The report embodies some miscellaneous points of interest arising during the initial stages of an investigation into the boot and shoe industry. It contains an historical introduction and an illustrated description of the principal processes, followed by two short sections bearing on fatigue and efficiency. The first of these deals with variations in output during the day for certain operations, and in it two inferences are drawn, first, that output on Saturday is always relatively low, and secondly, that the rate of production of a skilled worker is more regular and tends to fall later in the week than that of a worker whose skill is less or who is ill-suited to his work. The final section of the report is devoted to an account of an experiment with regular rest pauses in a certain pressroom, by means of which the average output from six presses was increased by 44 per cent. without the addition of new machines and with a reduction in the working hours of the individual operative.]

No. 11.—Preliminary Notes on Atmospheric Conditions in Boot and Shoe Factories, by W. D. HAMBLY, B.Sc., and T. BEDFORD. (70 pages, with plates). [Price 3s. net, post free 3s. 2d.]

[This report is concerned with the practical use of the kata-thermometer as an indicator of atmospheric conditions from a physiological aspect, and is based upon observations taken in 35 boot and shoe factories under varying conditions, and also in an aircraft doping room. It is a preliminary step towards the investigation of the relation of atmospheric conditions to fatigue and efficiency.

The report begins by enumerating the atmospheric conditions which are physiologically desirable (as enunciated by Dr. Leonard Hill). After a description of the kata-thermometer and its use, the observations in the various factories are discussed, and a comparison drawn between single storey and multi-storey buildings in regard to atmospheric conditions. The conclusions reached are summarised in the report, which is illustrated by detailed tables. In an appendix the uses of frequency curves are explained.]

E.—Pottery Series.

No. 18.—Two Investigations in Potters' Shops, by H. M. VERNON, M.D. (assisted by T. BEDFORD). (74 pages, with plates). [Price 2s. 6d. net, post free 2s. 8d.]

[Part I embodies the results of an investigation into the atmospheric conditions of potters' shops, in regard both to temperature and to cooling-power as measured by the kata-thermometer. The effects of the different types of stove are discussed, and the conditions in potters' shops are compared with those found in other types of factory.

Part II deals with the effect on atmospheric conditions of different types of stove, and in particular with extent to which hot air is admitted in the work-rooms. It also contains the results of experiments on the relative importance of temperature and air velocity in the drying of moist ware, and suggestions are made for improvement of the conditions.]

F.—Laundry Series.

No. 22.—Some Studies in the Laundry Trade, by MAY SMITH, M.A. (v and 57 pages, with plates). Price 2s. 6d. net, post free 2s. 8d.]

[This report embodies the results of an extensive survey conducted into the conditions of work in the laundry trade, and is based partly on actual observation of workers performing certain operations and partly on the application to workers of a psychological test. The atmospheric conditions of laundries explored by means of the kata-thermometer are also discussed, and a comparison is drawn between laundries and factories in other industries. Finally, suggestions are made, showing how certain improvements can be effected. Detailed instructions for using the kata-thermometer are appended.]

II.—OTHER PUBLICATIONS.

BEDFORD, T. (1922) : The Ideal Work Curve.—*J. Ind. Hyg.*, **4,** 6.

FARMER, E. (1922) : Time and Motion Study.—*Ibid.*, **4,** 5.

HAMBLY, W. D., and MCSWINEY, B.A. (1922) : The U-tube Manometer Test with relation to Muscular Exercise.—*Proc. Physiol. Soc., Oct.* 21, 1922.

HILL, L., VERNON, H. M., and HARGOOD-ASH, D. (1922) : The Kata-Thermometer as a Measure of Ventilation.—*Proc. Roy. Soc.*, B. **93,** 198.

MUSCIO, B. (1920) : Fluctuations in Mental Efficiency.—*Brit. J. Psych.*, **10,** 4.

MUSCIO, B. (1921) : Is a Fatigue Test Possible ?—*Ibid.*, **12,** 1.

MUSCIO, B. (1921) : Feeling Tone in Industry.—*Ibid.*, **12,** 2.

MUSCIO, B. (1922) : Motor Capacity with special reference to Vocational Guidance.—*Ibid.*, **13,** 2.

RUSHER, E. A. (1922) : The Statistics of Industrial Morbidity in Great Britain.—*J. Roy. Stat. Soc.*, **85,** 1.

STURT, M. (1922) : A comparison of Speed with Accuracy in the Learning Process.—*Brit. J. Psych.*, **12,** 3.

VERNON, H. M. (1921) : The Influence of Atmospheric Conditions on Industrial Efficiency.—*J. State Med.*, **29,** 353.

VERNON, H. M. (1921) : The Influence of Fatigue on Health and Longevity.—*J. Ind. Hyg.*, **3,** 3.

VERNON, H. M. (1922) : Atmospheric Conditions in Industry.—*Ibid.*, **4,** 8.

VERNON, H. M. (1922) : The Influence of Rest Pauses and Changes of Posture on the Capacity for Muscular Work.—*J. Physiol.*, **56,** 6.

WALLER, A. D., and DE DECKER, G. (1921) : The Physiological Cost of Muscular Work measured by the exhalation of Carbon dioxide.—*Brit. M. J., May* 7, 1921.

WILSON, D. R. (1921) : Some Effects of Environment on Efficiency and Safety.—*J. Roy. San. Inst.* **42,** 3.

WILSON, D. R. (1921) : The Work of the Industrial Fatigue Research Board.—*J. Roy. Soc. Arts*, **70,** 3660.

WYATT, S., and WESTON, H. C. (1920) : A Fatigue Test under Industrial Conditions.—*Brit. J. Psych.*, **10,** 4.

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LIST OF PUBLICATIONS

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The following publications relating to the work of the Medical Research Council can be purchased through any bookseller, or directly from H.M. Stationery Office, at the following addresses: Imperial House, Kingsway, London, W.C. 2, and 28 Abingdon Street, London, S.W. 1; 37 Peter Street, Manchester; 1 St. Andrew's Crescent, Cardiff; or 120 George Street, Edinburgh.

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No. 46. An Investigation into the Epidemiology of Phthisis in Great Britain and Ireland, Part III. By John Brownlee. Price 2*s*. 6*d*., post free 2*s*. 8*d*.

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Milk and its Hygienic Relations. By Janet E. Lane-Claypon. Price 9*s*. net. [Longmans, Green & Co.]

The Amoebae living in Man. By Clifford Dobell. Price 7*s*. 6*d*. net. [Bale, Sons, & Danielsson, Ltd.]

The Intestinal Protozoa of Man. By Clifford Dobell, and F. W. O'Connor. Price 15*s*. net. [Bale, Sons, & Danielsson, Ltd.]

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